Journal of
Experimental Psychology

VOL. 23, NO. 3 SEPTEMBER, 1938

THE RELATIONSHIP OF THE SIZE OF THE SURROUNDING FIELD TO VISUAL ACUITY IN THE FOVEA[1]

BY M. BRUCE FISHER

Rhode Island State College

Among the numerous variables which determine the nature of the visual process one of the more recent to come under quantitative investigation has been the condition of the retina apart from the region the function of which is being directly measured. The growing interest in this field has had both a theoretical and a practical motivation. Approached from the view of illuminating engineering, the brightness distribution in the visual field is important in many aspects of modern life. This orientation has led chiefly to a study of the effects of glare sources in the field of view. On the other hand, attempts at theoretical formulation of the visual process have so far failed to be completely satisfactory, perhaps because none of them has adequately included the factor of the surrounding field. Even in the restricted field of the photosensory process, the most valuable formulation, that of Hecht (**23**), fails at more than one point to account for the data; and the importance of the omission from his equation of any term descriptive of the condition of the retina outside the area tested is

[1] The writer is indebted to Professor Robert T. Ross and to Professor Walter R. Miles for guidance during the course of this experiment and for valuable criticisms and suggestions in the preparation of the manuscript.

This work was submitted to the faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

recognized by him in a more recent statement (**24**) that his equation describing the brightness difference limen will fit only those data taken under a specified condition of the surrounds. The constants of such an equation apparently involve a parameter which is worth attention for its own sake.

The present investigation was planned to study the effects of gross changes in the size of the surrounding field on foveal acuity. This is a kind of situation which has received little attention heretofore. The most relevant work is that of Cobb and Geissler (**14**); Cobb (**12**) and Lythgoe (**27**) who give results with acuity as the tested function when the brightness of a homogeneous field, filling the subject's view apart from the test object, was the significant variable. Their results indicated that acuity increases with the brightness of the surrounds up to a point just below equality with the test object, and thereafter decreases rapidly.

Two studies with other functions than acuity should be mentioned. Fry and Bartley (**16**) have repeated and confirmed the earlier work of Blachowski (**10**) showing that the difference threshold between a small central area and a larger field surrounding it, decreases as the size of the larger field is increased, up to four degrees of visual angle. Hecht and Smith (**25**) have studied the relation between critical fusion frequency and illumination when a flickering test patch was surrounded by illuminated fields of a brightness equal to that of the fused test patch. They found important differences in the fusion value when the size of the surrounds was increased from 5° to 30°. In the work to be reported here acuity was measured at three widely separated brightnesses when the illuminated part of the surrounding field was varied in size and brightness through wide limits.

Apparatus and Procedure

The general scheme of the apparatus is shown in Figure 1. The subject looked through an artificial pupil, *AP*, to a hole in the center of a white disc, *D*, which was at a distance of 80 cm from his eye. He saw, beyond it, part of the field of an Ives grating, *G*, (11) distant 120 cm, which served as test object. This was the identical grating used by Benedict, Miles, *et al.* (**9**). It shows a system of parallel lines whose width and separation are quickly and accurately adjustable by turning a micrometer wheel. It has the further advantage that the mean brightness of its field remains constant at all

separations of the critical detail. The lines of the test object, in this instance, were seen against a white screen, *S*. This screen was illuminated by a 500 w. projection lamp, L_1, which was movable along the length of the lamphouse. Photographic plate filters in front of this lamp produced the major variations in the brightness of the test object. Further adjustment was obtained by moving the lamp. The brightnesses of test object used (mean brightness of the face of the grating) were 104.8, 3.35, and 0.064 c per sq m and were measured with a Macbeth illuminometer. The surround screen, *SS* in Fig. 1, through which the subject viewed the test object, was of black velvet backed by heavy black paper, and had a reflection coefficient, in the direction of the subject's eye, of less than 0.001. On this screen were mounted four 2.5 v. lamps, *LOV*, at 90° intervals on a circle with a radius of 22° of visual angle around the subjects'

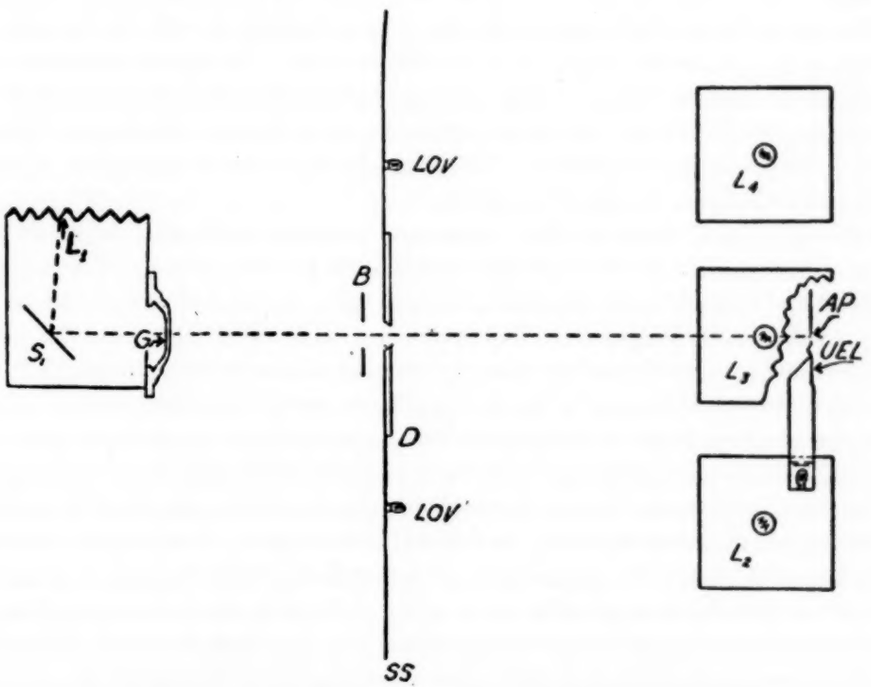


FIG. 1. Diagram of apparatus. Described in text.

line of sight. These 'limit of view' lights were run at a voltage barely sufficient to make their filaments glow. Their use is indicated below.

The discs, *D*, which served as experimental surrounds were cut from ply-board. The central aperture was afforded by a brass washer, set in the board, with a hole accurately machined to a diameter which would subtend 2° at the eye. The hole was sufficiently tapered on the side toward the grating so that it would not reflect to it any illumination received from the sources which illuminated the surrounds. Five sizes of disc were used, whose radial widths, beyond the central openings, were 2.5°, 5°, 7.5°, 12.5° and 20° of visual angle. The discs were painted with a high-reflectance magnesium oxide paint and presented a practically homogeneous field to the eye of the subject. They were placed at a position considerably nearer the subject than the test object in order to avoid the cues which are available when its limiting boundary is in the same plane as its face (9). As used in this experiment, the boundary of the test object, provided by the edge of the hole in the disc, could not be clearly imaged on the retina when the eye was accommodated for its lines. This hazy border was coincident

with that part of the retina whose condition could not be controlled in any case because of slight involuntary eye-movements.

The discs were illuminated by three sources, L_2, L_3, and L_4 in Figure 1, at points 120° apart on a circle of 40 cm radius around the subject's line of sight. These sources were 500 w. or 50 w. lamps, enclosed in boxes fronted with ground glass and diaphragm screens, by which five levels of brightness were produced in the surrounds: 2846, 104.8, 3.35, 0.064, and 0.0188 c per sq m. These brightnesses produced retinal illuminations of 8560, 318, 10.07, 0.193, and 0.0566 photons, respectively.[2]

An artificial pupil of 2 mm diameter was used before the tested eye. Placed close in front of the unused eye was a ground glass screen (*UEL* in Fig. 1), 7 × 4.5 cm, having a dim constant source behind it such that its brightness was about at the cone threshold.

The four principal light sources (L_1, L_2, L_3, and L_4) were run off the same line which was kept at approximately 105 v. by a suitable resistor. There were main-line voltage fluctuations of the order of 2 or 3 volts during a minute but the consequent fluctuations in brightness and color are considered to have had no general effect upon the results except to increase the variability. The ratio between the brightnesses of the surrounds and test object remained constant.

The test object, 'limit of view' lights and artificial pupil were set up in a fixed relation to one another so that a nearly reproducible position of the subject's eye could be secured by having him get the 'limit of view' lights just out of sight in the periphery before making each judgment. This procedure controlled not only the subject's distance from the test object but also the relation of the entrance pupil to the optic axis, a factor which Stiles and Crawford (34) have shown to be important.

In the ideal condition of adaptation for this experiment the different parts of the retina would be in an equilibrium state for the illuminations they were receiving. The presentation of a bipartite field to the subject's eye involved a considerable problem in maintaining the fixation necessary to fulfill this condition. The subjects were given instructions concerning the importance of maintaining their fixation as near to the center of the test object as possible, even when their accommodation was relaxed, and they were told to report whenever they realized they had looked away. After-images were demonstrated to them and they were shown how any border at the junction of surrounds and test object was a signal that fixation was beginning to wander. A variety of fixation points was tried but as they neither improved acuity nor reduced variability and were a source of distraction to the subjects they were dispensed with. Furthermore, with all but the lowest test object brightness, any fixation point at the distance of the grating presented discernable serrations at its edge before the lines were visible. It was to avoid this kind of cue that the discs had been placed nearer than the grating. When the test object and surrounds were both at 0.193 photon they were indistinguishable so that subjects 'lost' the hole when the larger discs were in

[2] The values of the retinal illumination given here and elsewhere in this report are calculated by the equation:

$$E = AB \times 10^{kA},$$

where E is the retinal illumination in photons, A is the area of the entrance pupil in sq mm (equal to π with a 2 mm pupil), B is the external brightness in c per sq m, and k is a mean value of − 0.006 taken from the data of Stiles and Crawford (34). This mean value is used in lieu of elaborate determination which would otherwise have to be made on each subject.

place. In this case a small rectangle of black paper, supported against the grating by a fine wire, served as fixation point.

A four-minute working period was first used but this was later extended to eight minutes when the subjects were found able to maintain fixation for that period.

The method of limits was used but half the standard procedure was omitted, the limen being approached only from below. Several considerations made this seem advisable. There is no possibility of introducing a confusion situation into the approach to the limen from above, comparable to that afforded by the differing positions of the lines which are possible with the Ives grating, when the approach is from below. When the disappearance of the lines must be responded to, after-images complicate the judgment, especially when the test object is bright. Furthermore, the subjects were uniform in their lack of confidence in judgments of 'disappearance.' Since the determination of absolute values of acuity was not part of the purpose of this experiment there was no necessity for including the approach to the limen from above and it was therefore omitted entirely.

The work was done in two-hour sessions, in any one of which the illumination conditions remained constant and thresholds were obtained with varying sizes of surrounds. The discs were used in balanced order, proceeding from the largest to the smallest and then from the smallest to the largest. There were two exceptions to this order. With the test object at 10.07 photons and the surrounds at 0.193 photon the complete balancing was secured by using different orders with different subjects. With the test object at 318 photons and the surrounds at 10.07, an irregular but balanced order was used.

At the beginning of each session the subject was dark adapted for five minutes. At the completion of half the balanced order described above he was given a rest period of five minutes in the dark. Readings were taken in sets of 15, making a total of 30 threshold measurements on each subject for each experimental condition. The lines of the test object appeared equally often in each of three directions, vertical and thirty degrees to either side of vertical. In each set of 15 measurements, five were made with the lines in each direction, in a chance order. Each set was preceded by one minute of light-adaptation to the conditions about to be used and followed by one minute of rest in the dark, a time during which the experimenter changed the surrounds discs. For the light-adaptation, the test object was illuminated before the surrounds, to provide a fixation point. During the light-adaptation and the readings that followed, the subject maintained fixation on the center of the test object.

To secure any single reading the experimenter first turned the micrometer screw of the grating until the detail was well below the threshold and turned the carriage to one of the three positions. He then said 'Ready' to the subject who immediately turned his attention to the test object (he was already fixating its center) and tried to accommodate for its distance. The experimenter turned the micrometer screw of the grating at a constant speed until the subject signalled that he saw the lines. This he did by pressing a key, convenient to his hand on the pillar supporting the headrest, thereby lighting a small lamp before the experimenter. The experimenter stopped turning and the subject spoke which way the lines appeared to lie. If he was correct the experimenter indicated the fact and the subject was then free to relax his accommodation until the next ready signal. If he was incorrect the experimenter told him either to continue his attention while the lines were made larger, or to relax a moment before starting over. The former was done only when the lines were still at a size that was clearly beyond the region of uncertainty indicated by previous trials. After a correct

judgment had been made the experimenter read the micrometer scale, recorded it, turned the wheel till the lines were again below the subject's limen and set the carriage for the next trial, which followed immediately.

The micrometer wheel of the grating was turned at two standard speeds, 6 r.p.m. and 12 r.p.m., which were controlled by timing the passage of the graduations on the micrometer wheel with the ticking of a four-beat-per-second clock. The slower speed was used only when the range of measurements was near the bottom of the acuity scale. When the faster speed was used under these circumstances the grating would sometimes be turned to the end of the scale before the subject could respond. When the slower speed was used at the higher illuminations errors became frequent, thereby lengthening the time necessary to secure a limen. The faster speed also shortened the time taken by each reading. In order to make the acuity values secured with the two speeds comparable, a reaction time of 0.5 second, in terms of distance on the micrometer wheel, was allowed in recording the readings.

The strain of trying to accommodate for an invisible object made it necessary to allow the subject to terminate a trial whenever the continued effort caused discomfort or whenever his eye began to water. To limit the occurrence of such fatigue an arbitrary time limit of 15 seconds was set during which a judgment could be made. If the lines were not reported in this time, the trial was terminated and the next start was made with the lines at a wider setting.

Thirteen combinations of test object and surrounds brightnesses were used in the experimentation. With two exceptions each of the three test object brightnesses was used with each of the five surrounds brightnesses. The 0.0566-photon surrounds were not used with the 318-photon test object, nor the 8560-photon surrounds with the 0.193-photon test object. In the latter instance acuity was too low to be measured with any size of surrounds.

Six subjects served in the experimentation. Five were male undergraduate students who were paid for their services. Their ages ranged from 19 to 22 (median, 21). The sixth was a woman, aged 29. None had ever worn glasses or had any history of eye trouble. All subjects had normal color vision according to the Ishihara Color Perception Test and had acuities of 1.75/1.75 in meters (5.75/5.75 in feet) or better, on the Snellen scale. Five subjects were given a modification of the Miles A-B-C Vision Test of Ocular Dominance (**30**). The other subject had taken the test previously, understood its purpose, and claimed to be ambiocular. His right eye was used. Three subjects were right-eyed and one definitely left-eyed according to the test. The dominant eye was used in each case. One subject was ambiocular by the test but was definitely right-handed and expressed a preference for the use of the right eye in sighting. His right eye was used in the experimentation.

The experimental sessions of each subject were always at the same time of day. They were excused when not in good health or especially fatigued.

Treatment of Results.—It became evident early in the investigation that not every reading was a 'good' one in the sense that it represented the best that the subject could do at the moment. This was evidenced by occasional extremely low readings frequently accompanied by remarks of the subject to the effect that the lines of the test object were much coarser, when he finally saw them, than he was able to distinguish. The reason for this is probably to be found in the lack of a fixation object and the consequent fluctuation of the accommodation distance of the lens. If this distance was 120 cm when the lines reached the physiologically-determined retinal threshold the best possible acuity value was obtained. Attainment of this accommodation any

later gave a poorer value of the acuity. In this sense, then, most of the values were less than they might have been under ideal circumstances. It follows also that if the optimal accommodation distance is achieved very late after the physiological threshold has been passed, the acuity measure will be abnormally poor. Therefore, in addition to the 15-second time limit referred to above, a further arbitrary selection was made in the treatment of the data. It will be remembered that the data were taken in groups of fifteen readings, each group made up of three sets of five readings, and each set being the readings taken with the lines of the test object in one of the three positions. It may be noted here that the ranges of these sets, being determined in part by the astigmatism of the eye, frequently did not overlap. Any reading which deviated as much as 2.5 A.D.[3] from the mean of its set of five was discarded, an error of that size being considered the result of factors which this experiment was not intended to measure. The readings were scanned as soon as a group was completed and if it appeared likely that one would be thrown out, an extra was taken at the time. This extra was not used in determining the limen unless calculation showed the suspected reading did not fulfill the criterion of being less than 2.5 A.D. from the mean of its set.

In the calculation of the results, the Mean and the Average Deviation of the ten readings in each position of the lines were found. The average of these three means

---

[3] The limit of 2.4999 . . . A.D. seems small but the maximum ratio of a single deviation to the Average Deviation is equal to half the number of cases in the distribution, which is 5/2 or 2.5 in the present instance. The presence of this limit can be demonstrated by considering a distribution of n scores in which all the scores but one lie on the same side of the mean. If $d_1, d_2, d_3, \ldots d_n$ are the deviations, regardless of sign, of a series of scores, $X_1, X_2, X_3 \ldots X_n$, then by definition,

$$\text{A.D.} = \frac{d_1 + d_2 + d_3 + \ldots d_n}{n}. \tag{1}$$

But if d_1 be the only score below (or above) the mean, then

$$d_1 = d_2 + d_3 + d_4 + \ldots d_n \tag{2}$$

and substituting in (1)

$$\text{A.D.} = \frac{2d_1}{n}. \tag{3}$$

From which,

$$\frac{\text{A.D.}}{d_1} = \frac{2}{n}, \quad \text{or} \quad \frac{d_1}{\text{A.D.}} = \frac{n}{2}. \tag{4}$$

If more than one score (*e.g.*, two scores) lie below (or above) the mean, then instead of (2) we have:

$$d_1 + d_2 = d_3 + d_4 + d_5 + \ldots d_n. \tag{5}$$

Correspondingly, for (3) we have

$$\text{A.D.} = \frac{2(d_1 + d_2)}{n} \tag{6}$$

and

$$\frac{d_1}{\text{A.D.}} = \frac{n}{2} - \frac{d_2}{\text{A.D.}} \tag{7}$$

From (4) and (7) it is evident that if only a single score lies to one side of the mean the ratio of its deviation to the Average Deviation is $n/2$, but that if more than one score lies in either direction from the mean the maximum ratio of a deviation in that direction to the Average Deviation is less than $n/2$.

was taken as the threshold value for a given stimulus condition. Its measure of variability was secured by averaging the three average deviations, converting this to a sigma value by the use of the formula S.D. = 1.2533 A.D., and dividing by the square root of the total number of cases (usually 30). The use of the Average Deviation as the base for the calculation of all measures of variability would not ordinarily be considered a thoroughly satisfactory statistical technique but a consideration of the small number of cases which were taken under comparable conditions in this experiment—a set of five—indicates that any more elaborate procedure would be useless or misleading. The measures of variability given are presented chiefly as an indication of their order of magnitude. The 'true' values for these measures would, almost certainly, be smaller than those here calculated, for the two sets of five readings, whose common Average Deviation is the basic measure for the final values, were separated in time by an interval of from six to ninety-eight minutes. The result was that the dispersion of the ten readings was sometimes as much as four times the size of that of either set of five alone, the physiological condition of the subject having changed sufficiently in the time interval to put his readings on a different part of the scale.

In four of the fifty-four gradients one of the limens necessary for the determination of a gradient was not completed in the two-hour session. In order to make these data usable in the calculation of the means for a group of subjects, each value that was lacking has been interpolated between the two adjacent points. For this purpose acuity values were plotted against the radial width of the surrounds and a linear relationship assumed.

The original data were recorded in scale units of the micrometer of the grating. After the calculations had been completed in these terms, the values were changed to acuity units according to an equation derived in the calibration of the grating. The straight-line relationship between acuity and scale reading, predicted for this instrument by Cobb (11), was found to hold so that no distortion was involved in dealing directly with differences in either scale or acuity units in any part of the range of either.

The Acuity Gradients

In Tables I, II and III the acuity of each subject and the mean acuity of all subjects for each of the experimental conditions are given. The results might have been presented in terms of millimeters of separation in the test object or on the retina, or in terms of the separation measured in visual angle. Any of the three measures has disadvantages because of the reciprocal relation between separation and acuity. Acuity has been used because it is the customary form of giving results and is that in which theoretical formulation has usually been made. All these methods give closely parallel results in the range of conditions used in this experiment.

The data would permit the construction of two other types of gradient beside that of acuity against size of surrounds. Either of the other two experimental variables, illumination

TABLE I

THE RELATION OF THE SIZE OF SURROUNDS TO ACUITY
(Low Test Object Brightness)

Illumination Conditions (Photons)	Subj.	Radial Width of Surrounds									
		2.5°		5°		7.5°		12.5°		20°	
		Ac.	σ_m	Ac.	σ_m	Ac.	σ_m	Ac.	σ_m	Ac.	σ_m
T.o.—0.193	Bi	.512	.013	.568	.008	.546	.009	.595	.008	.609	.008
Surr.—0.0566	Ma	.451	.008	.451	.009	.478	.013	.475	.011	.499	.013
	Mi	.585	.009	.580	.012	.564*		.531†	.012	.591	.011
	Na	.417	.009	.435	.013	.428	.014	.402	.010	.394	.006
	Mean	.491		.509		.504		.501		.523	
Difference from 2.5° value				+.018		+.013		+.010		+.032	
T.o.—0.193	Bi	.312	.011	.312	.007	.331	.007	.318	.010	.286	.008
Surr.—0.193	Ma	.503	.015	.535	.010	.539	.008	.505	.012	.486	.015
	Mi	.469	.014	.439	.014	.471	.012	.456	.017	.471	.009
	Na	.290	.007	.284	.007	.275	.007	.269	.005	.258	.007
	Mean	.394		.393		.404		.387		.375	
Difference from 2.5° value				−.001		+.010		−.007		−.019	
T.o.—0.193	Ma	.521	.012	.518	.009	.505	.007	.529	.008	.557	.009
Surr.—10.1	Mi	.613	.010	.609	.015	.591	.015	.578	.013	.548†	.011
	Na	.546	.009	.527	.005	.525	.009	.514	.007	.449	.009
	Mean	.566		.551		.540		.540		.518	
Difference from 2.5° value				−.015		−.026		−.026		−.048	
T.o.—0.193	Bi	.318	.008	.344	.009	.331	.008	.292	.005	.335	.009
Surr.—318	Ma	.471	.013	.408	.013	.351	.012	.314	.008	.271	.006
	Mi	.398	.016	.365	.011	.402	.015	.365	.009	.324†	.009
	Na	.378	.005	.353	.005	.372	.006	.308	.008	.294	.005
	Mean	.391		.368		.364		.320		.306	
Difference from 2.5° value				−.023		−.027		−.071		−.085	

* Interpolated value.
† $N = 15$.

of the surrounds and of the test object, might be used as the baseline, but in consideration of the way in which the data were collected, only the first mentioned is significant. The number of subjects or the number of readings with each subject would have to be considerably increased to make one day's results comparable with another's and only the size of the surrounds was varied in a single session.

TABLE II

THE RELATION OF THE SIZE OF SURROUNDS TO ACUITY
(Medium Test Object Brightness)

Illumination Conditions (Photons)	Subj.	Radial Width of Surrounds									
		2.5°		5°		7.5°		12.5°		20°	
		Ac.	σ_m	Ac.	σ_m	Ac.	σ_m	Ac.	σ_m	Ac.	σ_m
T.o.—10.1	Bi†	1.098	.017	1.114	.014	1.110*		1.103	.018	1.123	.009
Surr.—0.0566	Ka†	1.217	.012	1.209	.011	1.217	.012	1.213	.010	1.217	.014
	Mi	1.082	.018	1.051	.018	1.060	.013	1.098	.012	1.116	.012
	Na†	1.043	.010	1.060	.015	1.068	.010	1.152*		1.129	.012
	Tr	.924	.010	.908	.010	.939	.009	.935	.011	.969	.013
	Mean	1.073		1.068		1.079		1.100		1.111	
Difference from 2.5° value				−.005		+.006		+.027		+.038	
T.o.—10.1	Bi	1.117	.013	1.131	.014	1.114	.015	1.184	.011	1.217	.010
Surr.—0.193	Ka	1.247	.017	1.232	.010	1.213	.014	1.211	.012	1.215	.015
	Ma	1.109	.014	1.068	.014	1.028	.007	1.080	.010	1.084	.020
	Mi	.963	.018	.944	.026	.963	.022	.969	.015	1.017	.021
	Na	1.017	.018	1.021	.014	1.064	.011	1.068	.013	1.114	.011
	Mean	1.091		1.079		1.076		1.102		1.129	
Difference from 2.5° values				−.012		−.015		+.011		+.038	
T.o.—10.1	Bi	1.191	.013	1.195	.009	1.187	.010	1.211	.010	1.157	.014
Surr.—10.1	Ka	1.159	.011	1.154	.010	1.168	.009	1.178	.013	1.187	.013
	Ma	1.174	.012	1.193	.009	1.174	.007	1.176	.015	1.174	.010
	Na	1.058	.009	1.073	.009	1.077	.013	1.068	.015	1.144	.020
	Mean	1.146		1.154		1.152		1.158		1.166	
Difference from 2.5° value				+.008		+.006		+.012		+.020	
T.o.—10.1	Bi	.965	.019	.955	.019	.996	.015	.974	.014	.955	.017
Surr.—318	Ka	1.219	.010	1.206	.011	1.135	.010	1.148	.011	1.139	.009
	Ma	1.133	.006	1.107	.007	1.098	.011	1.073	.009	1.127	.009
	Mi	.985	.014	.935	.016	.972	.023	.871	.017	.929	.017
	Na	1.012	.008	.978	.008	.969	.009	.946	.010	.939	.006
	Mean	1.063		1.036		1.034		1.002		1.018	
Difference from 2.5° value				−.027		−.029		−.061		−.045	
T.o.—10.1	Bi	.658	.014	.684	.021	.686	.020	.815	.026	.815	.025
Surr.—8560	Ka	.886	.007	.808	.011	.813	.014	.774	.010	.744	.008
	Ma	.779	.009	.759	.010	.776	.009	.761	.012	.742	.009
	Mi	.722	.014	.729	.010	.705	.012	.630	.010	.634	.014
	Na	.681	.010	.625	.012	.604	.006	.617	.011	.529	.012
	Mean	.745		.721		.717		.719		.693	
Difference from 2.5° value				−.024		−.028		−.026		−.052	

* Interpolated value.
† Not balanced order.

The steps in the gradients are better measured in absolute differences than in percentages. This form of presentation

TABLE III

THE RELATION OF THE SIZE OF SURROUNDS TO ACUITY
(High Test Object Brightness)

Illumination Conditions (Photons)	Subj.	Radial Width of Surrounds									
		2.5°		5°		7.5°		12.5°		20°	
		Ac.	σ_m	Ac.	σ_m	Ac.	σ_m	Ac.	σ_m	Ac.	σ_m
T.o.—318	Bi	1.311	.019	1.378	.017	1.369	.017	1.412	.014	1.395	.014
Surr.—0.193	Ma	1.372	.011	1.365	.016	1.346	.011	1.383	.009	1.391	.009
	Mi	1.344	.017	1.354	.017	1.356	.014	1.333	.019	1.440	.018
	Na	1.260	.022	1.260	.015	1.335	.015	1.338	.016	1.369	.019
	Mean	1.322		1.339		1.352		1.367		1.399	
Difference from 2.5° value				+.017		+.030		+.045		+.077	
T.o.—318	Bi	1.473	.011	1.451	.015	1.479	.009	1.494	.014	1.503	.011
Surr.—10.1	Ma	1.369	.010	1.350	.015	1.404	.009	1.404	.008	1.348	.013
	Mi	1.331	.010	1.331	.008	1.337*		1.350†	.014	1.340	.009
	Na	1.356	.020	1.256	.022	1.243	.016	1.281	.014	1.338	.012
	Mean	1.382		1.347		1.366		1.382		1.382	
Difference from 2.5° value				−.035		−.016		0.0		0.0	
T.o.—318	Bi	1.402	.011	1.352	.020	1.359†	.019	1.290	.018	1.369†	.013
Surr.—318	Ma	1.434	.009	1.430	.008	1.428	.009	1.421	.009	1.430	.009
	Na	1.184	.012	1.227	.013	1.206	.011	1.230	.015	1.223	.011
	Mean	1.340		1.336		1.331		1.314		1.341	
Difference from 2.5° value				−.004		−.009		−.026		+.001	
T.o.—318	Bi	1.399	.011	1.412	.010	1.426	.012	1.417	.010	1.385	.013
Surr.—8560	Ma	1.387	.006	1.363	.006	1.391	.005	1.395	.005	1.331	.010
	Mi‡	1.249	.012	1.256	.010	1.240	.012	1.215	.014	1.217	.015
	Na	1.356	.007	1.335	.014	1.288	.019	1.295	.011	1.245	.009
	Mean	1.348		1.342		1.336		1.328		1.295	
Difference from 2.5° value				−.006		−.012		−.020		−.053	

* Interpolated value.

† $N = 15$.

‡ $N = 24$ for each limen of this subject.

does not overemphasize the differences produced at the lowest illumination of the test object, when the level of acuity was low and the changes produced were proportionately larger

than at the two higher illuminations. Both methods give the same general result.

In Figs. 2, 3 and 4 the mean acuities for each condition of illumination are plotted against width of surrounds as dif-

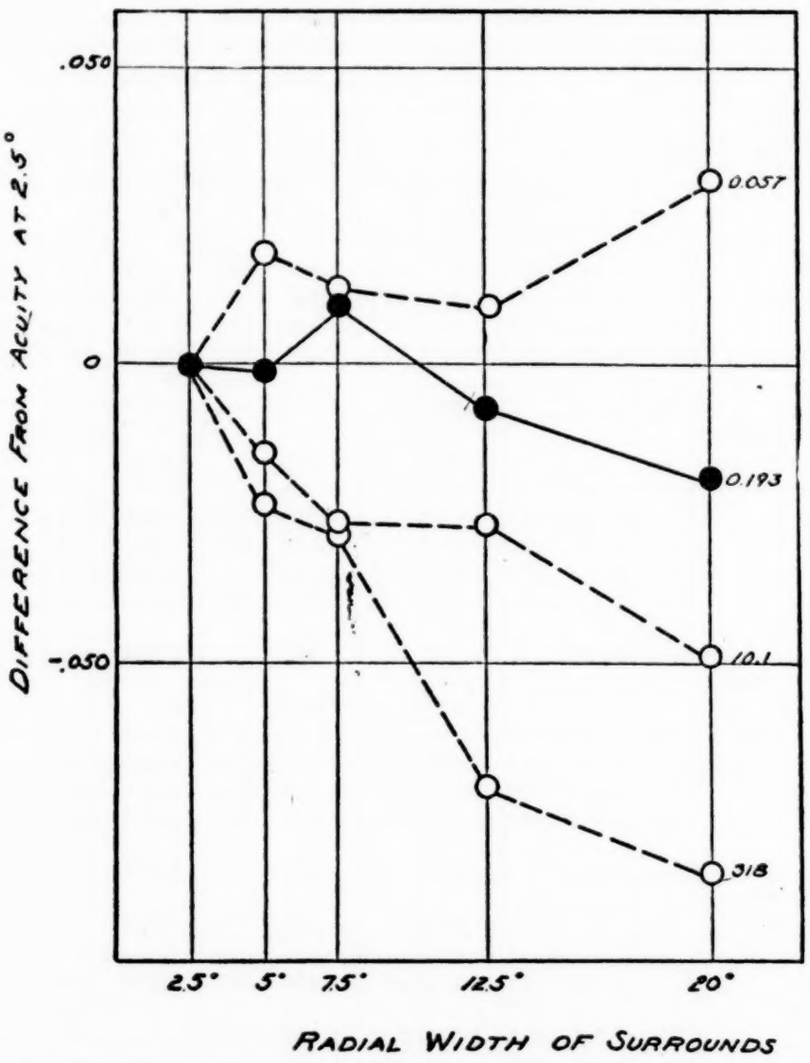


FIG. 2. Changes in acuity with varying sizes of surrounds. Test object brightness: 0.064 c per sq m (0.193 photons). The retinal illumination of the surrounds is indicated for each curve. The solid curve is that with surrounds and test object of equal brightness. Ordinates are absolute differences from acuity with 2.5° surrounds. Data from Table I.

ferences from acuity with the 2.5° surrounds. In Fig. 5 all these data are summarized in three curves showing the changes in acuity with size of surrounds when the brightness of the surrounds is less than, equal to, and greater than, that of the test object. One gradient in Table III, that with test object

at 318 photons and surrounds at 10.07 photons, is not plotted in Fig. 4 or included in the summations from which Fig. 5 was constructed. This gradient has been referred to before as one which was taken with a different balanced order than the others. Although there was no *a priori* reason for expecting any unusual results, the 2.5° value is badly out of the line of the other points. It is an extreme case of what is apparent

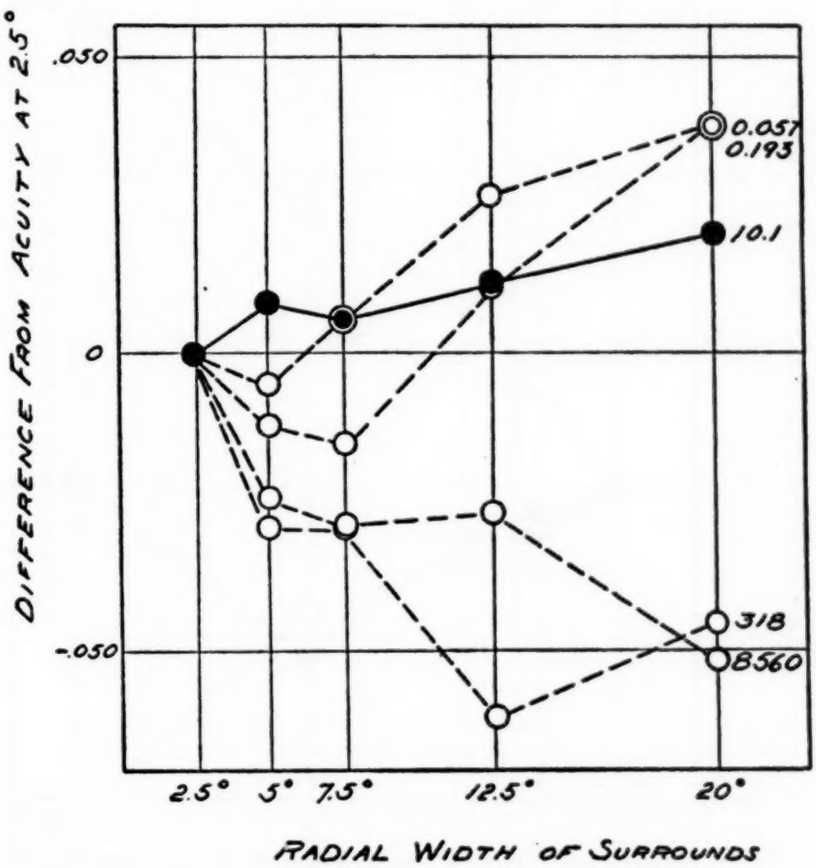


FIG. 3. Changes in acuity with varying sizes of surrounds. Test object brightness: 3.35 c per sq m (10.1 photons). Data from Table II. See Fig. 2 for explanation.

in the two curves with the 10.07-photons test object when the surrounds were dimmer, and, like them, its trend is in the characteristic direction, after an early break. Justification for this exclusion is to be found in the fact that the data for this gradient were taken under different conditions from the others and that the treatment given the data would have overweighted its peculiarities, minimizing the general result. It may be that this type of gradient is a significant finding,

but until further data are available by which to interpret it, separate treatment seems more advisable.

The general nature of the results is evident from the figures. When the surrounds are dimmer than the test object increasing their size improves acuity. When the surrounds

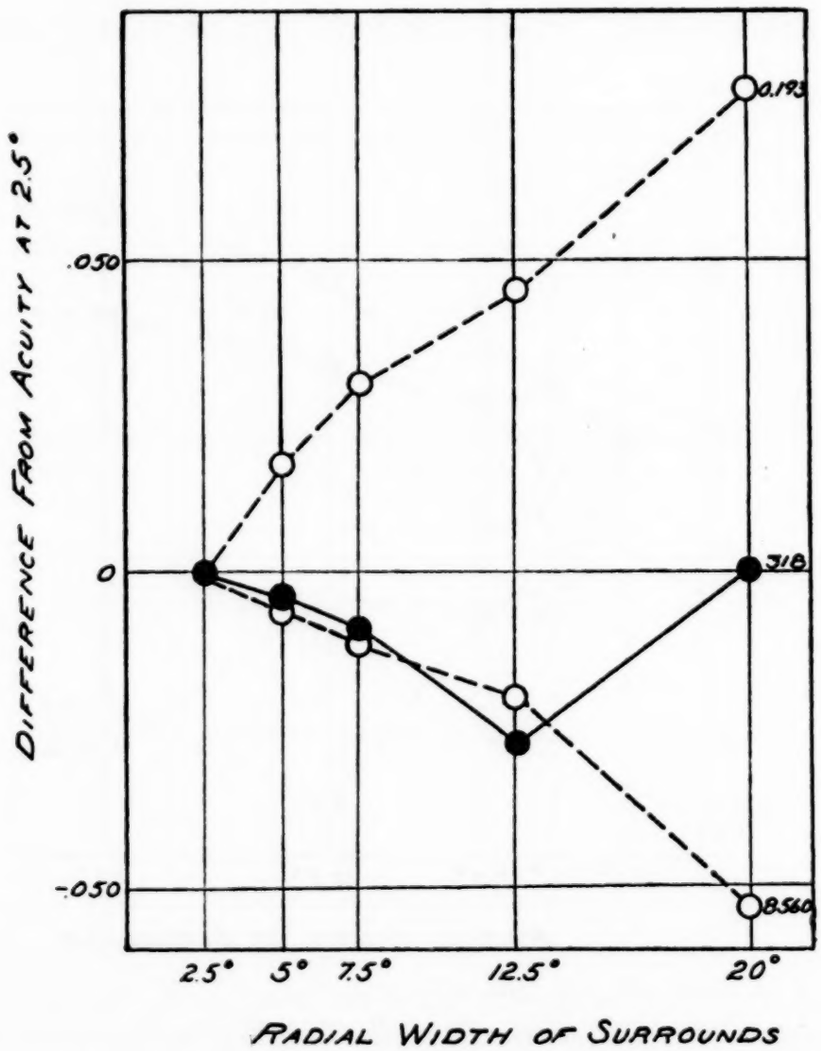


FIG. 4. Changes in acuity with varying sizes of surrounds. Test object brightness: 104.8 c per sq m (318 photons). Data form Table III. See Fig. 2 for explanation.

are brighter, acuity decreases with increasing size of surrounds. When surrounds and test object are of equal brightness, size of surrounds has no consistent effect. The most serious deviation from a horizontal line for an equal condition occurs when test object and surrounds are at 318 photons, a gradient based on only three subjects, one of whom accounts for almost all

of the deviation. This subject had been anomalous in one other gradient in this study and also was anomalous in some previous work on flicker, although this latter fact was not known to the experimenter until all the data were taken. During the session when his acuity on this gradient was measured this subject discovered some broad striations in the test

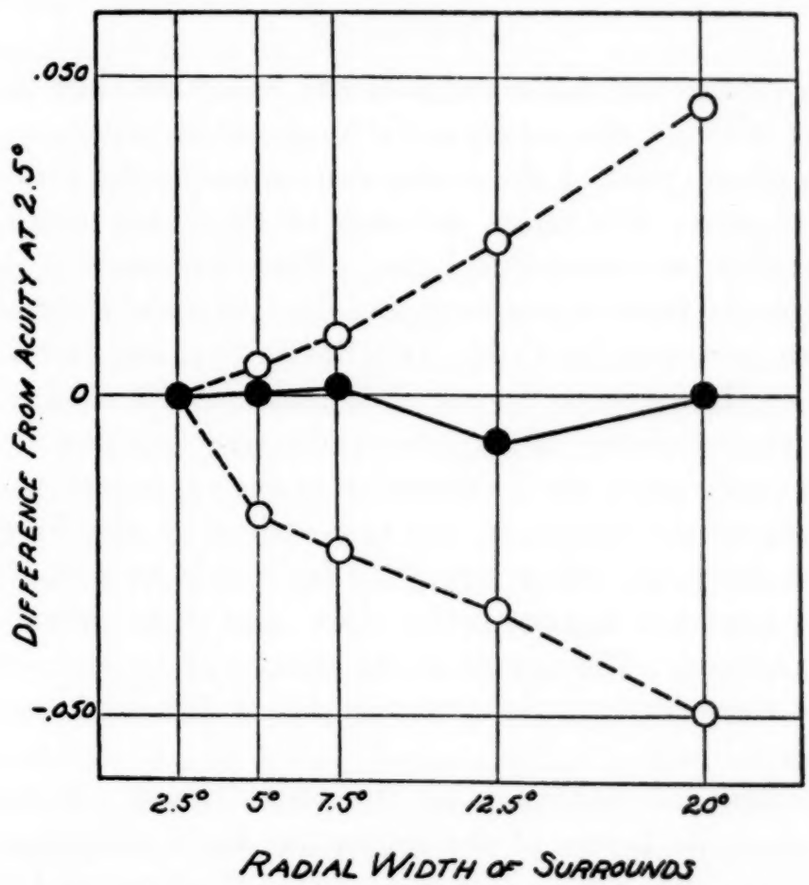


FIG. 5. Summary of changes in acuity with varying sizes of surrounds. The upper dotted curve is the mean of all the curves in Figs. 2, 3, and 4 in which the surrounds were dimmer than the test object. The lower dotted curve is the mean of all those in which the surrounds were brighter. The solid curve is the mean of the curves in which surrounds and test object were equal.

object which served as a cue to the 'slope left' position of the lines. They appeared in 90 percent of the trials in this position and were 100 percent reliable. Neither the experimenter nor any of the other subjects was able to see the phenomenon. He was an experienced subject when this occurred and in subsequent sessions was able to adjust successfully to instructions to disregard the cue and report the appearance of the

lines. Omission of his subsequent 'slope left' data from calculation changed neither the shape of his gradient nor the variability of his judgments, and they were therefore retained. The first appearance of this phenomenon was probably a sufficiently disturbing element to account for his peculiar results in that session.

Discussion

The discussion of these results will be undertaken from the point of view of the conceivable mechanisms whereby illumination of one part of the retina can influence the function of another part. The most evident of these are non-imaged illumination and scattered light. Their presence is deduceable from the facts of anatomy and dioptrics and their amount has been measured by Cobb (**11**), Bartley (**4**) and Bartley and Fry (**6**). The effect of such illumination will always be to reduce the efficiency of any discriminative function. In the present experiment the illumination of the surrounds would be scattered to the image of the test object at the fovea and produce there the effect described by Cobb, of reducing the percent contrast between the dark and light elements of the test object. The extent of the effect will depend upon the ratio of the scattered light to the direct illumination of the test object image.

A second mechanism is on the neural level. Interaction in the synaptic layers of the retina has been investigated by Granit (**21**), Granit and Harper (**22**), Graham and Granit (**20**), Geldard (**18, 19**), Beitel (**7, 8**), and Karn (**26**). The work oriented by this interest has concerned small areas and explanation has been in terms of the summation, facilitation and inhibition characteristic of the reflex activity of the spinal cord. The evidence for summation and facilitation is clear-cut but that for inhibition is by no means unequivocal. The results for whose explanation this principle has been invoked (**20**) (**8**) can as easily be explained on the basis of scattered light. The spatial limits for interaction which most of this work has set are of the order of three degrees in the periphery and a degree or less in the fovea.

In addition to retinal interaction there is also the possibility, not to say probability, of interaction at higher centers, in the colliculi or the cortex. This has been suggested by Bartley (**5**) to account for variations in the cortical reaction time produced by changes in the area of stimulus.

A third type of explanation of the interaction of the parts of the visual field has been suggested by Fry and Bartley (**16**) and named by them the 'border effect.' According to their analysis borders have effects upon one another depending upon whether they are parallel or perpendicular. This effect has a spatial limit of four degrees. Supporting evidence has been offered by Fry and Cobb (**17**) for very small separations.

A fourth type of mechanism, which will be most important for our discussion, was first suggested by Cobb (**13**) but the idea has been developed by Ross (**32, 33**) as the 'V-substance' hypothesis. It is an addition to the generally accepted description of the photosensory process as a reversible reaction whose equilibrium state is a function of the intensity of illumination. According to the hypothesis a material called 'V-substance' is produced from the blood stream, the retinal tissues, or perhaps from some more distant source, whenever there are present in the eye the decomposition products of the initial photosensory reaction. The creation of this supply of 'V-substance' would be a process similar to the inter-related secretions of the endocrine system and to the production of histamine in the 'triple response' of the skin. Its amount is determined by the amount of the decomposition products in the eye taken as a whole and it is freely diffusible through the retina. It acts to hasten the resynthesis of the photosensory substance and will therefore increase the efficiency of any function except the perception of the absolute threshold. We should expect, then, that any increase in the area or intensity of retinal illumination would produce this increase in efficiency, for it must increase the total amount of photo-products in the eye, and consequently, the amount of 'V-substance.' Considerable evidence in consonance with this hypothesis was to be found (**14, 12, 28, 20, 27**) when the surrounds were less bright than the test object. The evidence from the

same studies was, at first appearance, contradictory when the surrounds or secondary area was brighter than the test object.

In the interpretation of the results of this investigation it is evident that the concept of 'border effect' can be of little help. The spatial limits of the effect are too small. Interaction in the synaptic layers of the retina is of no greater assistance. The smallest size of surrounds used more than covers the area in which we should expect to find neural effects in the foveal region and they can therefore be considered as constant in the experiment. It would be possible to declare at this point that all the effects noted are the result of neural integrations at the level of the colliculi or higher. However, progress in our understanding here seems most likely if we seek explanations in terms of peripheral rather than central events, which are so much more difficult to experiment with, unless the data themselves make such explanations impossible. It is this point of view that leads to the attempt to account for the present data in terms of 'V-substance' rather than central facilitation and in terms of scattered light rather than central inhibition.

Turning then to the gradients of Fig. 5, we can say, in broad terms, that scattered light accounts for the negative gradient of acuity against size when surrounds are brighter than the test object, that 'V-substance' accounts for the positive gradient when surrounds are dimmer than the test object, and that the balancing of the two accounts for the constancy of acuity when the surrounds and test object are equally bright. If we note that scattered light operates to reduce acuity by reducing the percent contrast between the elements of the test object, it is apparent that when the surrounds are dimmer such influence will be at a minimum and that only as the level of the illumination of the surrounds approaches that of the test object will there be an appreciable effect. However, when the surrounds are brighter, proportionate increases will make larger changes in the contrast of the test object elements. To account for these data, then, we need to make only one further assumption: that the improvement in acuity, which is the result of the increased size or illumination of surrounds and which is achieved through the

action of 'V-substance,' bears a more nearly linear relationship to the amount of light falling on the eye than does the decrement from scattered light.

Other data on surrounds are amenable to the same explanation. The findings of Cobb (**12**), Cobb and Geissler (**14**), Lythgoe (**27**), and Lythgoe and Tansley (**28**) can be summarized as showing that the efficiency of a visual function increases slightly with increasing brightness of the surrounds up to approximate equality with the test object and thereafter

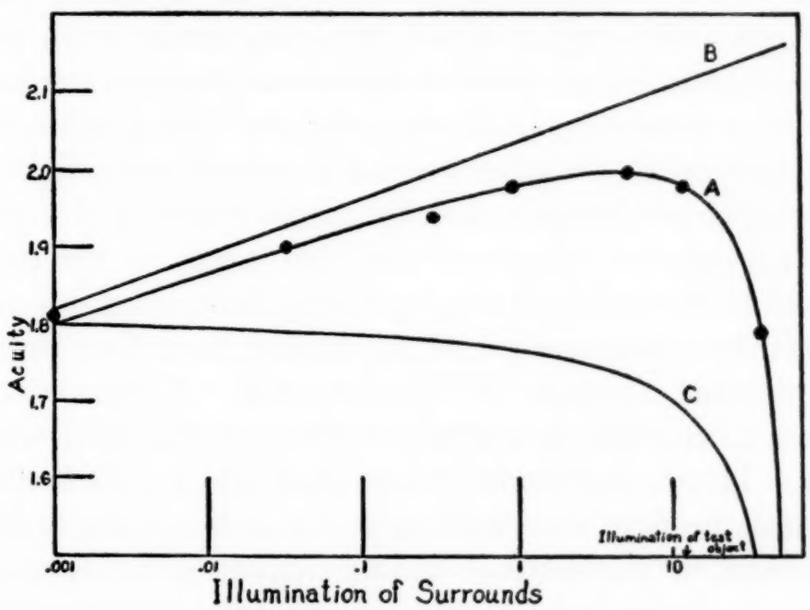


FIG. 6. A theoretical curve describing acuity data from Lythgoe (27, Table V). The equation of curve *A* is $Ac = .072 \log I_s + \frac{1}{10(\log I_s - 1.85)} + 2.035$. The two other curves show the slopes of its two components. Curve *B* indicates the hypothetical effect of 'V-substance'; curve *C*, that of scattered light. The constants of the equation were obtained by trial and error. The points are from Lythgoe. The point at which the illumination of test object and surrounds are equal is indicated.

decreases rapidly. This is what we would expect if, according to the foregoing discussion, the facilitation from 'V-substance' is a regularly increasing element in the situation, whereas the detrimental effect of scattered light is one that is minimal for a space but becomes rapidly dominant at a certain point in the scale. Figure 6 shows an empirical equation exemplifying this situation and fitted to some typical data, that of Lythgoe (**27**, Table V) on the variation of foveal acuity with the bright-

ness of the rest of the visual field. The constants of the equation were selected after a little trial and error and they could doubtless be corrected by a more elaborate fitting technique, but it is evident that this type of function gives a close approximation to the experimental findings. It is to be noted that the brightness is plotted in logarithmic units to bring the 'V-substance' curve into a straight line. This does not change the fundamental relationships between its slope and that of the scattered light curve.

Two other relevant studies are those of Cobb (**11**) and Hecht and Smith (**25**). Cobb, studying acuity with the Ives grating as test object, found a difference between the loss produced by an over-lying 'haze' and the loss produced by a bright light in the periphery which scattered some light to the foveal test object image. The less rapid loss in acuity with the peripheral light as compared with the 'haze,' as the two were increased in intensity, is the expected effect when one remembers that the strong peripheral light must have been producing a considerable amount of 'V-substance.' This was able to counteract, in some measure, the effect of the light scattered from it. Hecht and Smith found that when a flickering test patch and the field surrounding it are of the same brightness the relation of the critical fusion frequency to illumination followed the same law for both 5° and 30° surrounds through the middle range of brightnesses. However, as the upper limit of visibility is approached the frequency with the 5° surrounds reaches a maximum and falls off, whereas that with the 30° surrounds nearly maintains its maximum level. The 'V-substance' hypothesis is not designed to explain the decrement that occurs at high illuminations but the direction of the difference between the two curves is an effect that follows directly from a consideration of the implications of the hypothesis. It has been stated above that the presence of 'V-substance' will improve any retinal function except the perception of the absolute threshold. This exception occurs because any increase in the velocity of resynthesis of the photosensory substance will prevent some retinal elements, which might otherwise have done so, from reaching their thresholds. It is

evident that 'V-substance' itself exerts two contrary influences although the improvement by reason of increased reactility of functioning elements outweighs the loss from the prevented function of others in all but this one case. In Hecht's situation we need to bear in mind these two influences as well as the effect of scattered light. At very high illuminations we would expect the negative influence of 'V-substance' to be at a minimum, for if the assumption be made that the thresholds of the retinal elements are approximately normally distributed with respect to the logarithm of the illumination, then, toward the upper limit of vision, very few elements would be driven below threshold by the increase in 'V-substance' with 30° over 5° surrounds. In this case the increment to the frequency value from the increased reactility of functioning elements would be the significant result of the presence of surrounds.

Among the purposes of this study was that of determining whether 'V-substance' was of any value at all in elucidating visual phenomena. So far the answer has been in the affirmative but a number of other problems still await answer. The area and intensity relations of surrounds to foveal function must be worked out in greater detail, and especially, its time relations must be determined if we are to differentiate central neural effects from peripheral physiological ones. A study of time relations may also suggest some answer to the question of the source of 'V-substance.'

Another group of problems concerns the relation of some color phenomena to surrounds. Révész (**31**) and Angier (**3**) have reported differences in the color threshold with changing brightness of surrounding field. Changes in the brightness difference threshold for spectral lights with variation in the color of adjacent areas reported by Martin (**29**) and Emerson and Martin (**15**), and the 'visual reflex' phenomena of Allen (**1, 2**) raise questions concerning the possibility of the existence of more than one type of 'V-substance,' produced by the activity of, or exerting specific influence on, different types of cone. If such were to be the case we might have here a contribution to a peripheral explanation of some types of color contrast.

Summary

Monocular acuity in a 2° foveal area was measured with an Ives grating at retinal illuminations of 0.193, 10.07 and 318 photons. A 2 mm artificial pupil was used before the tested eye and a field of low constant brightness was placed before the unused eye. The surrounds were annular in shape, their inner margins forming the boundary of the test object. There were five sizes of surrounds with radial widths of 2.5, 5, 7.5, 12.5 and 20 degrees of visual angle. The surrounds were illuminated separately from the test object and were used at retinal illuminations of 0.0566, 0.193, 10.07, 318, and 8560 photons. The method of limits was used, with approach only from below the limen. Data were taken in two-hour sessions in which the illumination conditions remained constant and the five sizes of surrounds were used in balanced order. Dark-adaptation, and one minute of light-adaptation to the conditions about to be used, preceded the taking of readings.

Six subjects with normal vision served in the experimentation and 7800 threshold measurements were made. Each test object illumination was paired with each surrounds illumination except that the lowest of each was not used with the highest of the other.

1. When the surrounds were brighter than the test object the acuity progressively decreased with increasing size of surrounds.

2. When the surrounds were dimmer than the test object the acuity progressively increased with increasing size of surrounds.

3. When the surrounds and test object were equally bright, increasing the size of the surrounds had no consistent effect on acuity.

The explanation of none of these results can be made on the basis of neural interaction in the retina because of the spatial limits of such effects. The decreasing acuity occurring when the surrounds are brighter than the test object can be explained on the basis of scattered light. In interpreting the improving acuity found when the surrounds are dimmer than the test object recourse is had to an hypothesis which involves

interaction on the physiological level. It is found to apply to the data of the present study and to that of others which involved the effect on a tested function of gross changes in the size or illumination of a secondary area.

(Manuscript received April 20, 1938)

References

1. Allen, F., On reflex visual sensations, *J. Opt. Soc. Amer.*, 1923, **7**, 583–626.
2. ——, The variation of visual sensory reflex action with intensity of stimulation, *J. Opt. Soc. Amer.*, 1926, **13**, 383–430.
3. Angier, R. P., Über den Einfluss des Helligkeitkontrastes auf Farbenschwellen, *Zsch. f. Sinnesphysiol.*, 1906, **41**, 343–363.
4. Bartley, S. H., The comparative distribution of light in the stimulus and on the retina, *J. Comp. Psychol.*, 1935, **19**, 149–160.
5. ——, The time of occurrence of the cortical response as determined by the area of the stimulus object, *Amer. J. Physiol.*, 1935, **110**, 666–674.
6. Bartley, S. H. and Fry, G. A., An indirect method for measuring stray light within the human eye, *J. Opt. Soc. Amer.*, 1934, **24**, 342–347.
7. Beitel, R. J., Jr., Spatial summation of subliminal stimuli in the retina of the human eye, *J. Gen. Psychol.*, 1934, **10**, 311–327.
8. ——, Inhibition of threshold excitation in the human eye, *J. Gen. Psychol.*, 1936, **14**, 31–61.
9. Benedict, F. G., Miles, W. R., *et al.*, Human vitality and efficiency under prolonged restricted diet, *Publ. Carnegie Instit. Wash.*, 1919, No. 280, pp. 701.
10. Blachowski, S., Studien über den Binnenkontrast, *Zsch. f. Sinnesphysiol.*, 1913, **47**, 291–330.
11. Cobb, P. W., The influence of the illumination of the eye on visual acuity, *Amer. J. Physiol.*, 1911, **29**, 76–99.
12. ——, The effect on foveal vision of bright surroundings. II, *Psychol. Rev.*, 1914, **21**, 23–32.
13. ——, The effect on foveal vision of bright surroundings. IV, *J. Exper. Psychol.*, 1916, **1**, 540–566.
14. Cobb, P. W. and Geissler, L. R., The effect on foveal vision of bright surroundings, *Psychol. Rev.*, 1913, **20**, 425–447.
15. Emerson, S. A. and Martin, L. C., The photometric matching fields. II. The effect of peripheral stimulation of the retina on the contrast sensibility of the fovea, *Proc. Royal Soc. Lond.*, 1925, **108A**, 483–500.
16. Fry, G. A. and Bartley, S. H., The effect of one border in the visual field upon the threshold of another, *Amer. J. Physiol.*, 1935, **112**, 414–421.
17. Fry, G. A. and Cobb, P. W., Visual discrimination of two parallel bright bars in a dark field, *Amer. J. Psychol.*, 1937, **49**, 76–81.
18. Geldard, F. A., Brightness contrast and Heymans' Law, *J. Gen. Psychol.*, 1931, **5**, 191–206.
19. ——, Foveal sensitivity as influenced by peripheral stimulation, *J. Gen. Psychol.*, 1932, **7**, 185–189.
20. Graham, C. H. and Granit, R., Comparative studies in the peripheral and central retina: VI. Inhibition, summation and synchronization of impulses in the retina, *Amer. J. Physiol.*, 1931, **98**, 664–673.

21. GRANIT, R., Comparative studies in the peripheral and central retina: I. On the interaction between distant areas in the human eye, *Amer. J. Physiol.*, 1930, **94**, 41–50.

22. GRANIT, R. AND HARPER, P., Comparative studies on the peripheral and central retina: II. Synaptic reactions in the eye, *Amer. J. Physiol.*, 1930, **95**, 211–228.

23. HECHT, S., Vision: II. The nature of the photoreceptor process. Chapter 14 in *Murchison, C. (ed.): A Handbook of General Experimental Psychology.* Worcester: Clark Univ. Press., 1934.

24. ——, A theory of visual intensity discrimination, *J. Gen. Physiol.*, 1935, **18**, 767–789.

25. HECHT, S. AND SMITH, E. L., Intermittent stimulation by light. VI. Area and the relation between critical frequency and illumination, *J. Gen. Physiol.*, 1936, **19**, 979–989.

26. KARN, H. W., The function of intensity in the spatial summation of subliminal stimuli in the retina, *J. Gen. Psychol.*, 1935, **12**, 95–107.

27. LYTHGOE, R. J., The measurement of visual acuity, *Med. Res. Coun., Sp. Rep. Ser.*, London, 1932, No. 173.

28. LYTHGOE, R. J. AND TANSLEY, K., The adaptation of the eye: Its relation to the critical frequency of flicker, *Med. Res. Coun., Sp. Rep. Ser.*, London, 1929, No. 134.

29. MARTIN, L. C., The photometric matching field, *Proc. Roy. Soc. Lond.*, 1923, **104A**, 302–315.

30. MILES, W. R., Ocular dominance demonstrated by unconscious sighting, *J. Exper. Psychol.*, 1929, **12**, 113–126.

31. RÉVÉSZ, G., Über die Abhängigkeit der Farbenschwellen von der achromatischen Erregung, *Zsch. f. Sinnesphysiol.*, 1906, **41**, 1–36.

32. Ross, R. T., Fusion frequency in different areas of the visual field, 1934. Ph.D. thesis deposited in the Sterling Memorial Library of Yale University, New Haven, Conn.

33. ——, A contribution to the theory of retinal reaction to intermittent stimuli, *Psychol. Bull.*, 1934, **31**, 710–711.

34. STILES, W. S. AND CRAWFORD, B. H., The luminous efficiency of rays entering the eye pupil at different points, *Proc. Roy. Soc. Lond.*, 1933, **112B**, 428–450.

THE EMOTIONAL RESPONSES: CHANGES OF HEART-RATE IN A GUN-SHY DOG

BY J. G. BEEBE-CENTER AND S. S. STEVENS

Harvard University

The present work represents an attempt to study visceral changes during marked emotions. Specifically, it is a study of changes in the heart-rate of a gun-shy dog, induced by various forms of emotional stimulation, especially shot stimuli. We chose heart-rate as an index of visceral change because it varies over a wide range of values and can be recorded objectively without markedly limiting the freedom of the animal. We experimented with a gun-shy dog because it was possible to induce in him marked emotional states by means of easily controlled stimuli, namely shots.

Heart-beats were recorded by means of a Western Union Undulator activated by amplified cardiac action-potentials. Electrodes were attached to either side of the dog's chest and the action-potentials were conducted to the amplifier through a shielded cord 70 feet long, which allowed continuous recording while the animal moved about in a region comprising most of the rooms in two stories of the house in which he lives. This freedom of movement made it possible not only to apply specific stimuli (*e.g.*, shots), but genuinely to vary the general situation (*e.g.*, to change the animal from the room where shots were fired to the bed-room where the animal was accustomed to sleep).

Before considering the effects of various stimuli we wish to call attention to the variability of cardiac rate. When the dog is lying at rest the rate of beating shows a marked rhythm which correlates with the animal's breathing. (Cannon and Moore (1) noted the same fact in cats.) The heart-rate averaged over 10 seconds will readily be 40 beats per minute slower than the fastest rate achieved during that interval, and 40 beats faster than the slowest rate. As the average heart-

rate increases, this variability of rate appears to persist.[1] (The rhythmic character of the heart-rate is evident in Fig. 2.)

Prior to the investigation of the effect of shots, we studied cardiac responses to a variety of other forms of stimulation, and correlated cardiac rates with various postures and move-

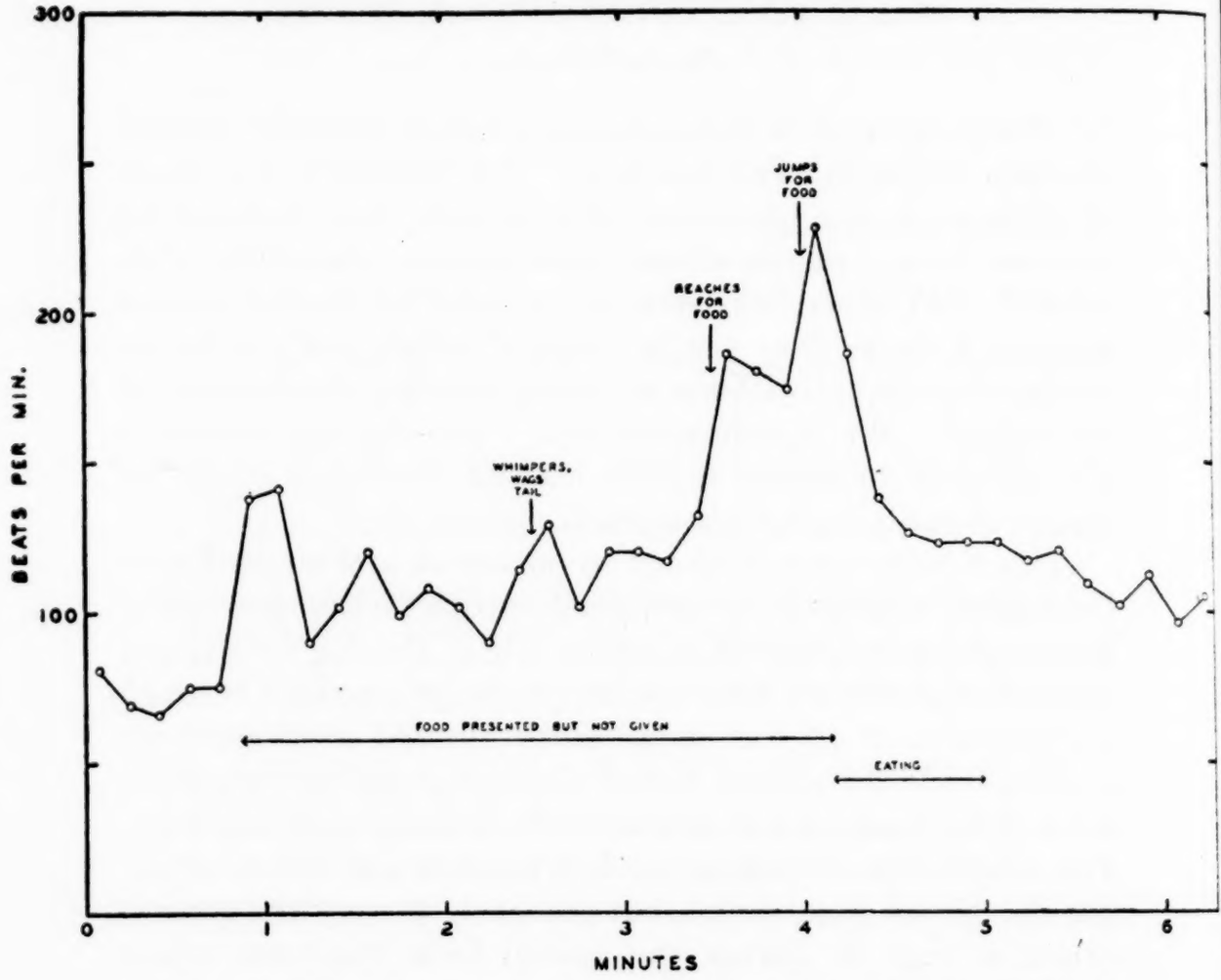


FIG. 1. Temporal course of cardiac response when the dog is first tantalized with food and then given it. The circles represent heart-rates, in beats per minute, averaged over 10-second periods.

ments. Table I gives some of the results of this exploratory work. The numbers are in all cases average rates for 10-second periods. All of the italicized numbers are from records taken while the stimulation persisted. Dashes indicate those

[1] The variability of low heart-rates in the dog is apparent from casual inspection of the tape-record. At high heart-rates this variability is not so apparent to inspection, but after the data have been converted into *rates* by taking the reciprocal of the time between beats, the variability emerges and is nearly as large for high as for low rates.

10-second periods where the rate could not be determined because the record was faulty.

When we compare the 'lying' rates with the 'standing' rates, omitting the first 10 seconds after stimulation which involve the activity of changing from one posture to the other, it is apparent that the differences are much less marked than those induced by most emotional stimuli. When, however, we consider the increases in heart-rate which accompany jumping, and also those which occur with the activity of standing up, it is clear that even minor exertion is reflected by changes in heart-rate comparable to those induced by many emotional stimuli. We find (1) that almost all of the emotional stimuli cause an increase in rate (there is a single case of slight decrease, but this is probably due to anticipation and habituation [2]); (2) that the increases range from a few beats per minute to well over twice the rate before stimulation; and (3) that in every case the rate is higher during the first 10 seconds than during the second 10 seconds.

In connection with this last fact, it should be noted that although during the first 10 seconds after stimulation there is a peak in the heart-rate, this is not necessarily the only peak. Indeed, in the case of one of the reactions to the withdrawal of the dog's mistress it is not even the highest peak. It is apparent that in most cases emotional increase of heart rate is not steady, but intermittent—it is not one response, but a series of responses. Whether or not the first peak is to be the highest depends upon the nature of the situation. Good proof of this fact is presented in Fig. 1, which shows cardiac acceleration when the dog is offered very desirable food, but is prevented from eating it for several minutes (frustration). The dog tries to get the food—gives up temporarily—tries again, etc., and eventually he whimpers and jumps excitedly. Some of these phases are indicated on the record (the timing is accurate only to about 5 seconds). It is obvious that in this reaction the highest heart-rate is not reached until just before the dog actually receives the food. Incidentally, it is inter-

[2] Habituation shows up strikingly in many of our data, but we shall postpone discussion of it until we have data relating it to the variables we think most likely to be relevant, namely the interval between stimulations and initial level of the heart-rate.

esting to note how the heart-rate decreases following the beginning of the consummatory response. It appears that the cardiac reaction is the accompaniment of a tension which increases gradually and then suddenly discharges. We have observed a similar feature in the reactions to shots.

Table I shows a concomitance between cardiac reaction and exertion in the case of changes of posture. The same concomitance is strikingly apparent in the emotional reactions which we have been discussing. All of them involve cardiac acceleration; they also involve skeletal activity. Furthermore, marked cardiac acceleration appears to correlate with violent (though perhaps brief) activity. An illustration of this effect is afforded in Fig. 1 by the peak in heart-rate just before eating, when the animal jumps for the food. Another illustration is the high heart-rate which follows occasionally upon the return of the mistress to the room and also upon the spoken words "Want to go out?" In both cases the dog jumps excitedly and shows extreme pleasure. A further illustration of the effect is the fact that the initial peak in heart-rate is accompanied by a major skeletal readjustment (*e.g.*, 'jumping up').

If the concomitance between cardiac acceleration and skeletal exertion is a general feature of emotional reactions, then our dog ought, in certain instances, to show fear accompanied by cardiac deceleration, for his skeletal reaction to a blow is a very passive 'cringing.' An experiment was performed in which the animal, while somewhat excited because of his proximity to the recording apparatus, was suddenly slapped hard and kept cowed for about 10 seconds by threatening remarks and gestures. This was done a total of five times. The fourth slap yielded an unreadable record. In the other instances, the average rate for 10 seconds after the slap was lower than that for 10 seconds before the slap. The reaction to the first slap, which yielded the best 'cowing' and the most marked deceleration, is represented in detail in Fig. 2, where the dots represent individual heart-beats. It is quite clear that 'fear,' in these cases, involves cardiac deceleration concomitant with 'being cowed.'

TABLE I

Cardiac Responses Accompanying Certain Postures, Activities, and Emotional Situations

The numbers represent heart-rates in beats per minute, averaged over 10-second periods. Rates measured during a particular posture, activity or emotional situation are printed in italics.

Identification of Record	Stimulus, Posture, or Activity	Beats per Min. for Two 10 Sec. Periods Preceding Stimulus		Beats per Minute for Successive 10 Sec. Periods after Stimulation. Persistence of Stimulation is Indicated by Italicized Numbers											
				1st	2d	3d	4th	5th	6th	7th	8th	9th	10th	11th	12th
Nov. 28	Lying (from sitting)	57	66	*54*	*54*	*57*	*54*	*51*							
Nov. 29		112	96	*102*	*84*	*72*	*66*								
Sept. 18	Standing (from lying)	67	61	*99*	*75*	*72*	*72*								
Nov. 29		66	78	*93*	*84*	*87*	*75*								
Nov. 28	Jumping (from standing)	66	96	*123*	103	93	93	90							
Nov. 29		105	84	*126*	*126*	99	84	90	84						
Sept. 17	Mistress leaves room	72	72	*120*	*90*	*72*	*78*	*114*	*87*	*84*	*102*	123	144		
Sept. 18, Rec. 1, Tr. 1		135	102	*123*	*108*	*96*	*90*	—	180	150	109	117	108		
Rec. 1, Tr. 2		105	108	*111*	*96*	*111*	—	*120*	147	132	108	102	108	102	
Rec. 1, Tr. 3		116	111	*132*	*99*	—	—	156	150	126					
Rec. 2		67	72	*102*	*84*	*60*	90	84	84						
Rec. 3		90	84	*81*	*78*	60	78								
Sept. 18, Rec. 1	Cat suddenly thrown into room	69	84	*174*	108	78	90	90							
		60	72	*141*	87	69	81	75	78	72	79	78	78	78	
Oct. 24	Anticipation of food	81	114	*135*	*123*										
Oct. 24	Eating meat bone	132	—	*162*	*138*	*156*	—	—	*144*	—	—	—	—	—	*135*
Nov. 2, Rec. 2	"Want to go out?"	90	93	*159*	*144*	*150*	108	87	108	108	111	99	90	102	99
Nov. 29		69	84	*168*	*159*	*84*	*159*	138	96	75	90	105	99	87	75

Let us now turn to the reactions to shots. Fig. 3 shows the initial phase of two such reactions. Zero on the abscissa indicates the moment of stimulation. For each reaction there are plotted the rates of the last beat before stimulation and of each beat thereafter for 10 seconds. Here again we find a maximal peak in the early part of the reaction—about the fifth second after stimulation. Two reactions starting from

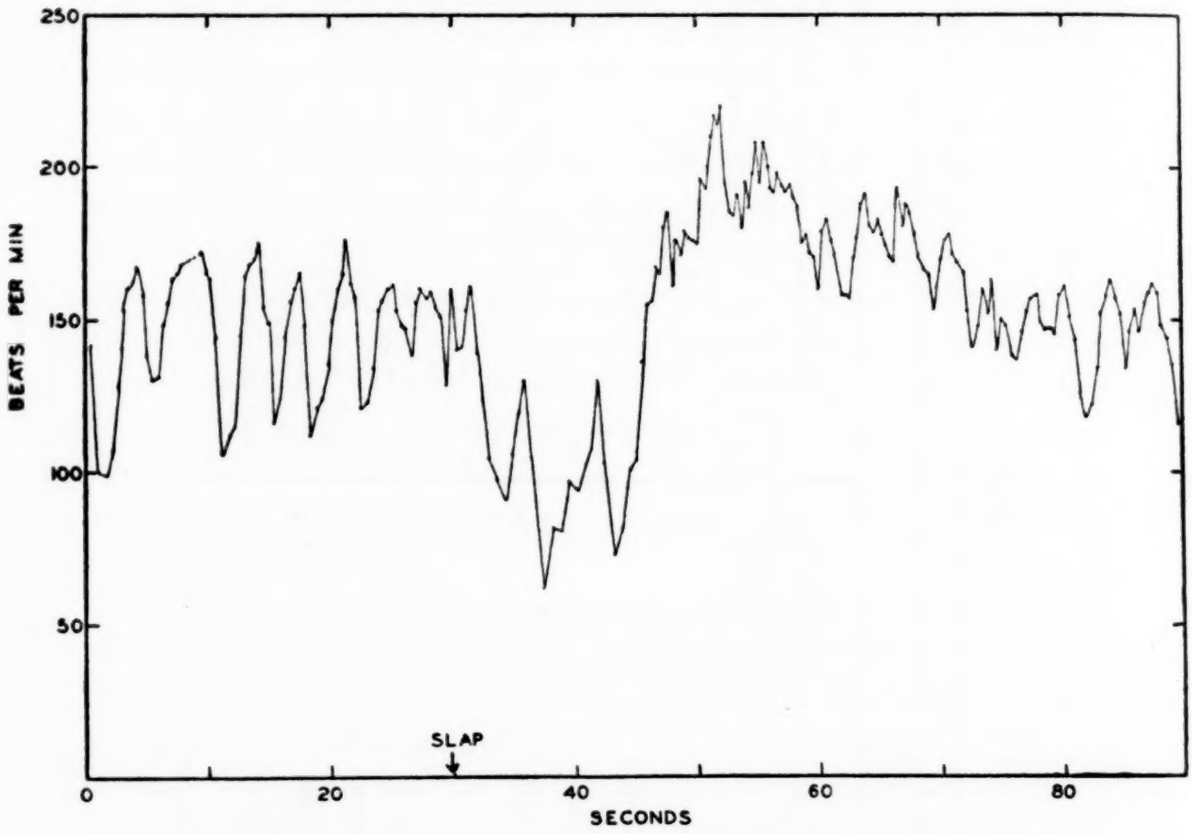


FIG. 2. Temporal course of cardiac response to strong slap, followed by threats which lasted about 10 seconds. The points represent rates of individual heart-beats, in beats per minute.

very different levels were chosen because they typify two extremes of the principal variation shown by the reactions. The terminal level of the reactions is remarkably constant, but those starting from a low level show a rapid rise of considerable magnitude, while those starting from a high level show a slow rise of small magnitude.

The relation between magnitude of rise and level from which the rise takes place is given for 16 reactions in Fig. 4.

In this figure, the increment in rate corresponding to the maximal peak of heart-rate (maximal in the sense that the next peak is lower) is plotted against the heart-rate averaged over 5 beats before stimulation.

Fig. 5 shows the course of cardiac acceleration observed in 14 reactions.[3] Here we have plotted the increment in heart-

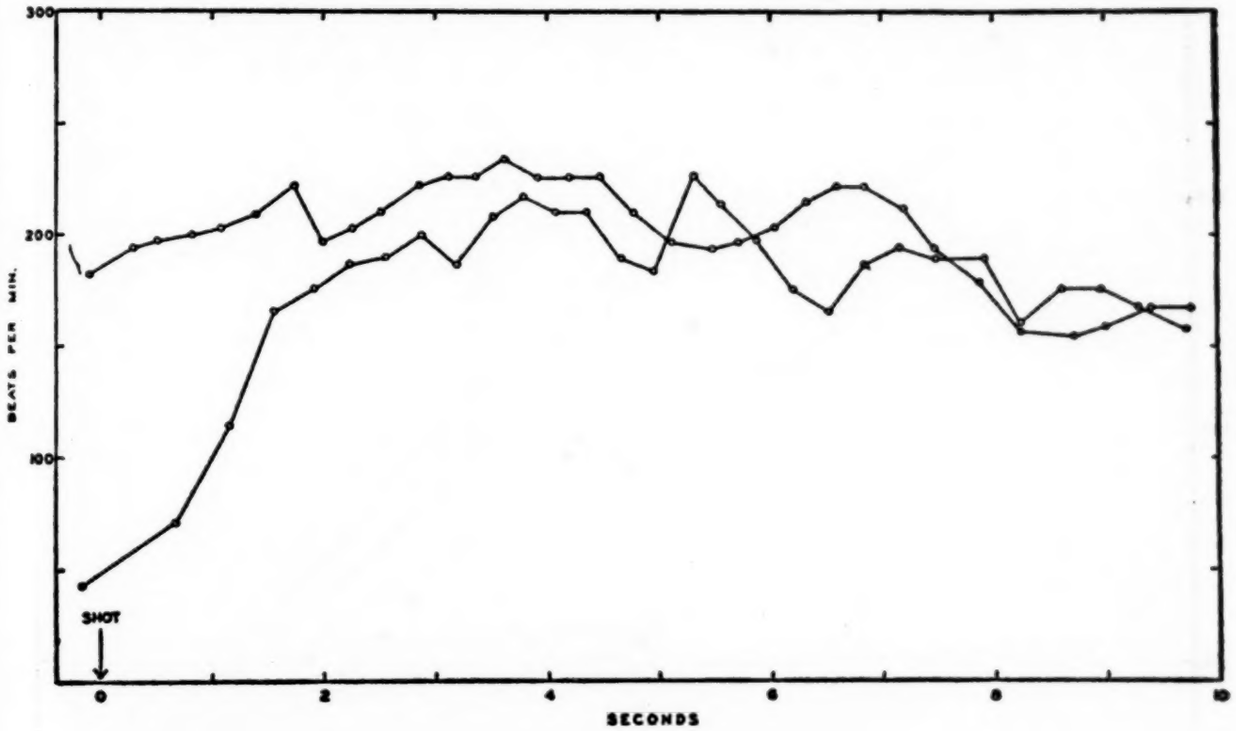


Fig. 3. Temporal course of the initial phase of two cardiac responses to shots, one starting from a high level of heart-rate, the other from a low level. The circles represent rates of individual heart-beats, in beats per minute.

rate (ordinate) against the time elapsed following a shot (abscissa). The circles represent successive peaks achieved in the course of the reaction and the last circle on each curve stands for the highest peak attained. Thus the uppermost curve pictures a reaction in which the heart-rate increased by 193 beats per minute in 3 seconds, declined somewhat, rose again until, after 4.2 seconds, the increment in rate was 214

[3] The reactions are the same as those in Fig. 4, except that one reaction is omitted from Fig. 5 because its initial phase was illegible and another because it showed a slight drop in rate rather than a rise. The occurrence of the drop was doubtless due to the fact that the last beat before the stimulus represented a high rate (212 per minute) and to the fact that the stimulus was the fourth shot fired during one session.

beats per minute, and then declined. The increase here is large because this reaction started from a low rate. The other reactions started from higher levels and show correspondingly smaller increments. It should be noted that the rate of rise (slope of the curves in Fig. 5) correlates with magni-

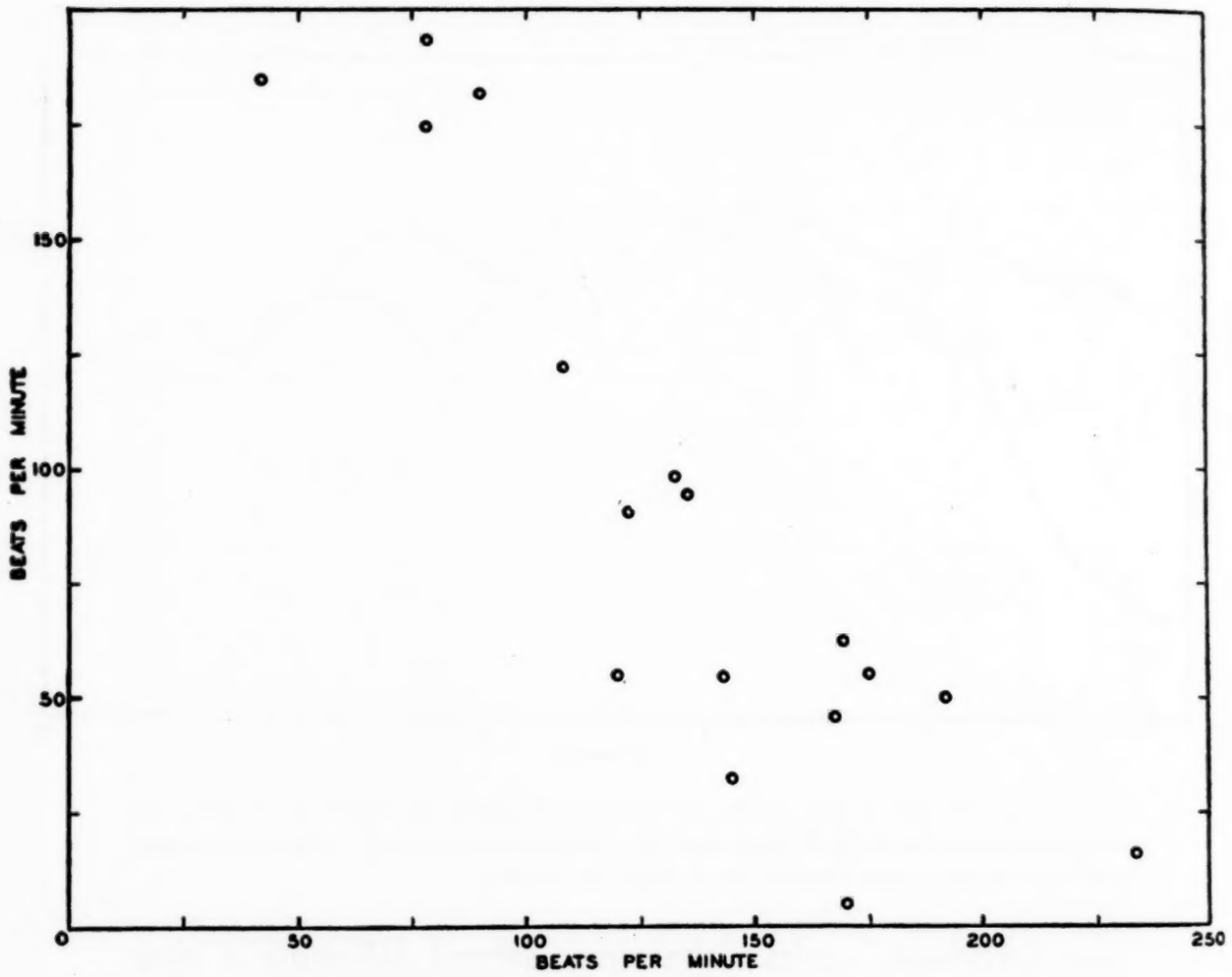


FIG. 4. Relation of increment in heart-rate elicited by a shot to initial level of heart-rate. The abscissa represents the average heart-rate for 5 seconds preceding the shot; the ordinate represents the increment from the rate for 5 seconds preceding the shot to the rate of the individual beat which constitutes the maximal peak (*i.e.* the next peak is lower).

tude of the rise both in the case of the average rate of rise to the maximal peak, and in the case of the rate of rise to the first peak. This correlation expresses the relative constancy of the action-time, which is defined as the time of positive acceleration after stimulation. Action-time, so defined, does indeed

increase with magnitude of response, but it varies only from 0.44 seconds to 2.96 seconds for rises varying from 7 to 193 beats per minute.

Figure 6 represents average heart-rate for 10-second periods before and after the firing of a shot. Each set of points is for a particular reaction. The figure includes only

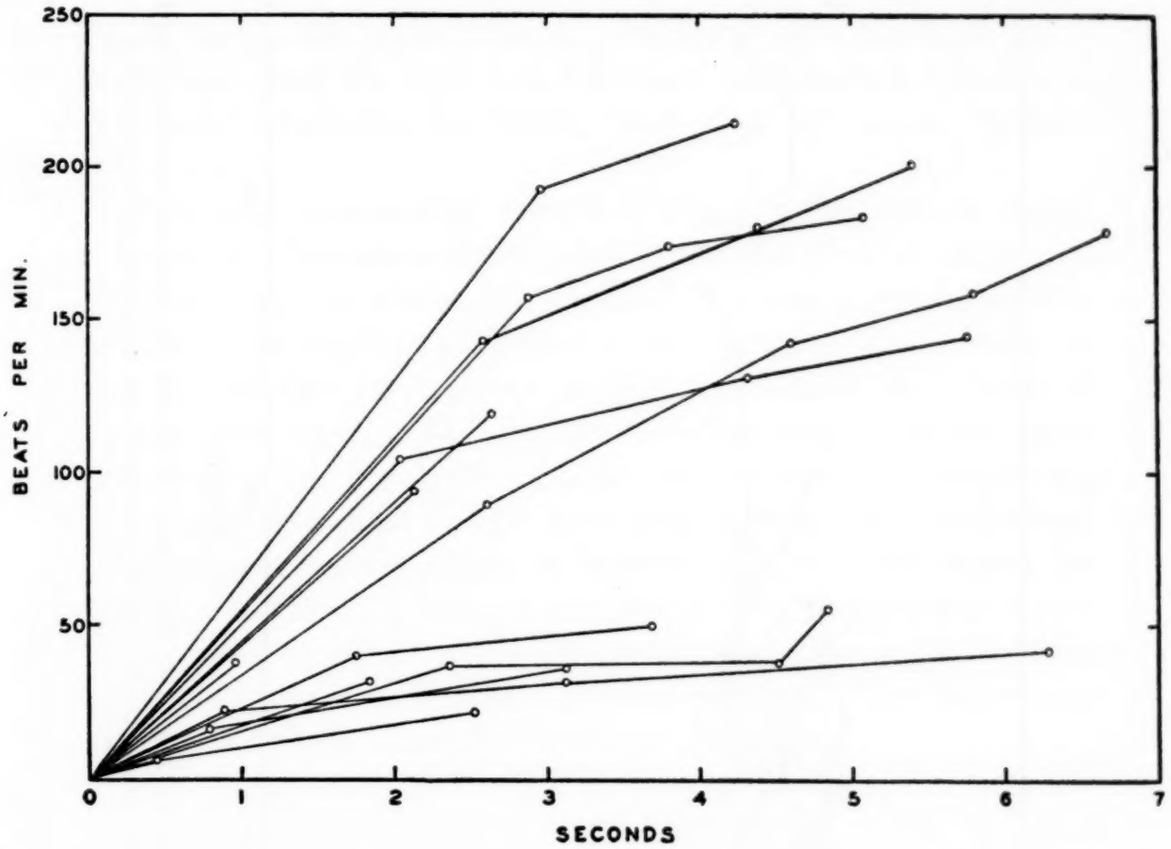


FIG. 5. The course of the rise in heart-rate for 14 individual reactions to a shot For each reaction the circles represent successive minor peaks in the heart-rate, and the last circle represents the peak which is maximal, in the sense that the next peak is lower. The ordinate measures the increment in heart-rate from the last beat before stimulation to the beat constituting a peak.

reactions to the first shot on any one experimental day. The broken line represents an illegible portion of record.

The most important feature of Fig. 6 is its demonstration of the persistence of the response to a shot *long after the cessation of the exciting stimulus.* In the cats, which we studied earlier, the reaction to a shot is essentially a brief one—in the nature of startle (**2**). In the dog, there is indeed a peak during

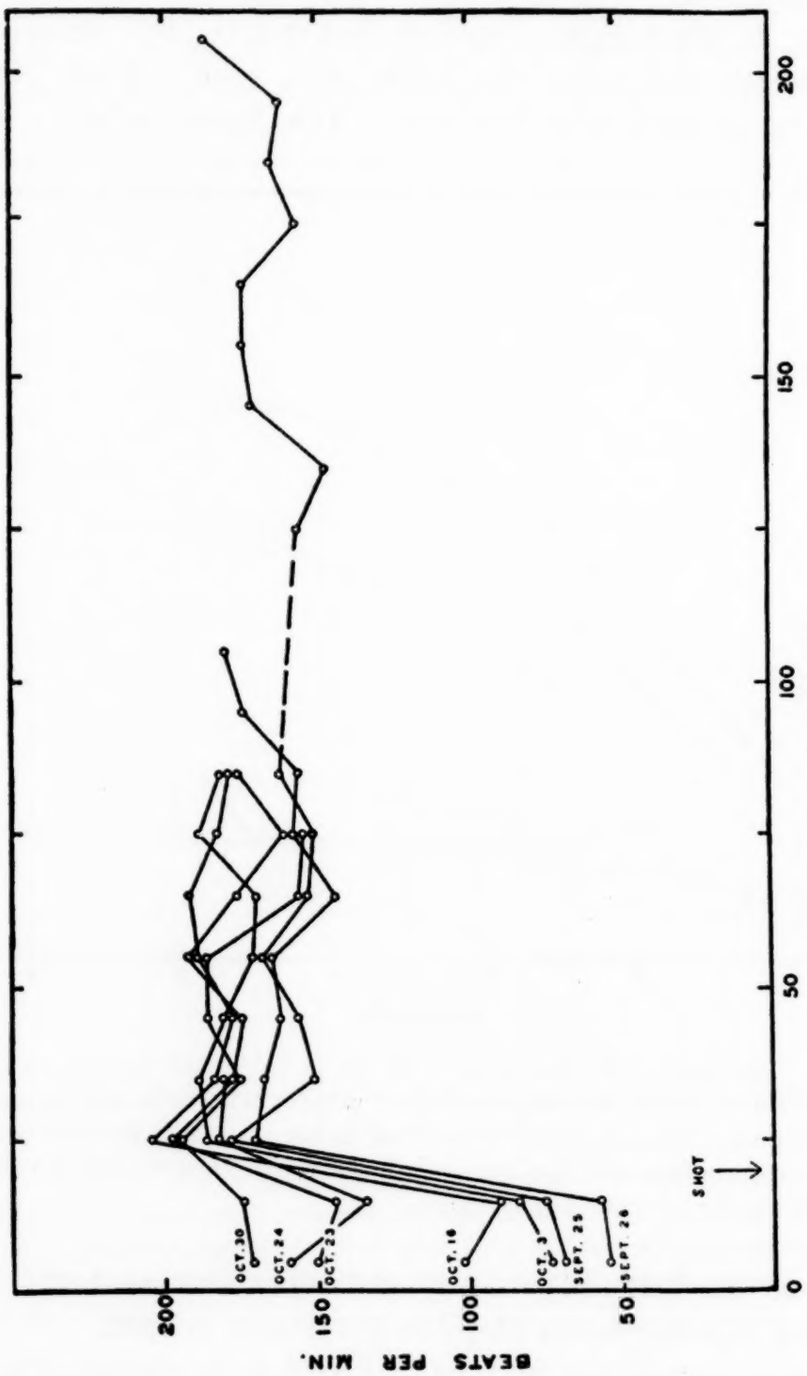


FIG. 6. Persistence of high level of heart-rate after a shot. The circles represent heart-rates averaged over 10-second periods. The dates on which the reactions occurred are indicated at the left of each curve.

the first 10 seconds, but this peak is followed by minor accelerations and decelerations about a level of from 150 to 200 per minute which persists until some change is introduced in the situation. In one case, it will be noted, such a high level is maintained for 3 minutes, at the end of which time the average heart-rate for 10 seconds is 186, a figure higher than that for any previous 10-second period, including even the period right after stimulation. Persistence of the high level is accompanied by a variety of overt movements which are obviously attempts at flight, and also by much violent shivering.

A second noteworthy feature of Fig. 6 is the way in which the reaction becomes conditioned upon the general situation. As shown by the dates, the level of heart-rate preceding the shot becomes higher and higher as the experiment proceeds, so that finally this level is but slightly lower than that induced by the shot itself. This gradual conditioning, however, does not account for the persistence of the reaction, for persistence is strikingly evident on the very first occasion of stimulation.

A third feature, which is evident to the most casual inspection, is that it is not the amount of rise in heart-rate which is relatively constant from one reaction to the next, but the ultimate level to which the heart-rate rises. The heart-rate reaches a ceiling near 180 beats per minute.

We have seen that in the absence of change in conditions the reaction persists at a high level for as much as three minutes. Genuine relief, however, results in a prompt drop in level of heart-rate, together with cessation of attempts at flight. Fig. 7 represents deceleration after the return of the dog to the bedroom in which he is accustomed to sleep (3 cases), and after feeding, with subsequent return to the bedroom (1 case). The small part of the graph on the left of the break represents the heart rate at rest before the experiment. The arrow represents the beginning of relief. Average rates for 30-second periods are plotted against time, except for the 30-second periods immediately preceding and following relief, where the averages are for the 10-second periods nearest the beginning of relief and for the adjacent 20-second periods.

Each line represents one reaction. Broken lines represent interpolations made where the record was marred.

The two smooth curves are reproduced from articles by Rosenblueth and Simeone (3) (*A*) and Cannon and Britton

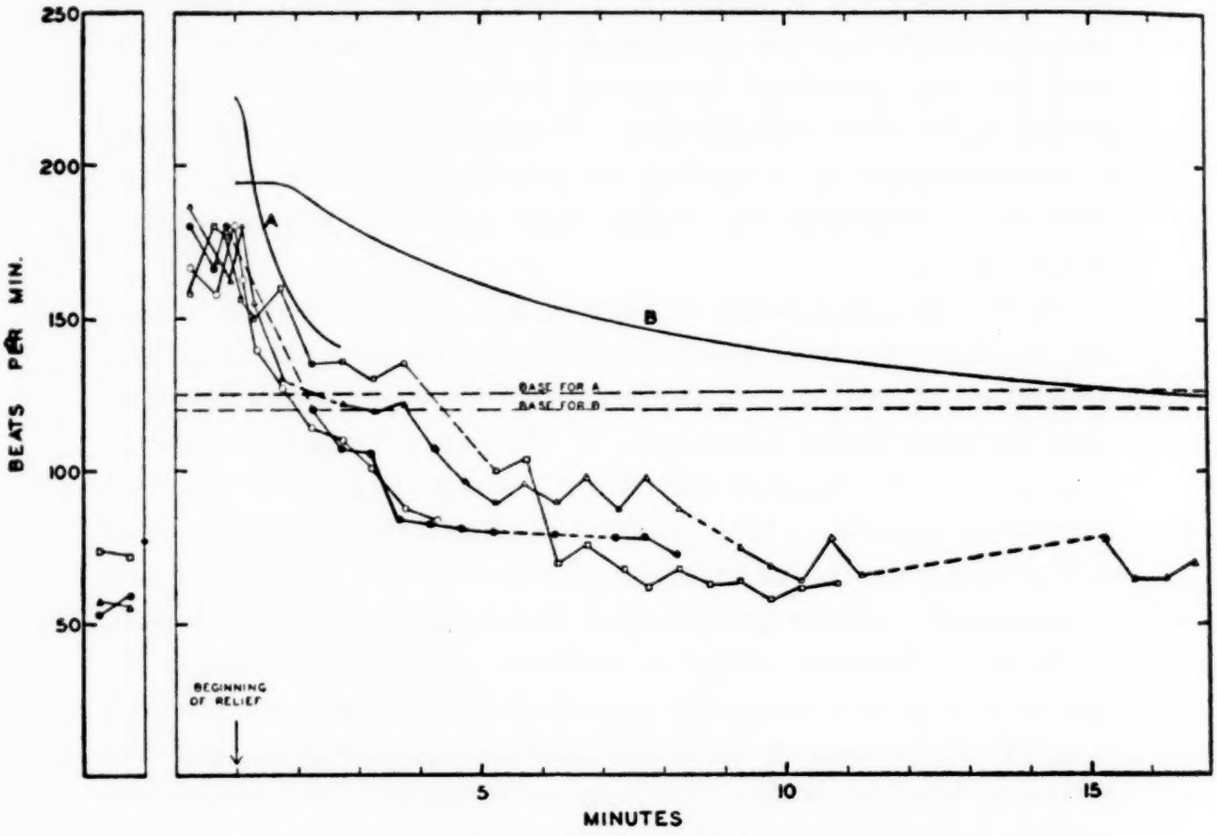


FIG. 7. Temporal course of cardiac deceleration after the beginning of relief. Circles, dots, squares and triangles represent heart-rates averaged over 30-second periods, except for the 30-second periods preceding and following the beginning of relief, in which case the averages are for the 10 seconds nearest this moment and for the next 20 seconds. Abscissa values represent mean times. The narrow graph on the left represents the resting heart-rates before any emotional stimulation.

Curve *A* (reproduced for comparison from A. Rosenblueth and F. A. Simeone) represents cardiac deceleration after the cessation of stimulation of the right accelerator of the cat by a maximal electrical stimulus at 8 per second for 30 seconds. Base *A* represents the heart-rate before this stimulation.

Curve *B* (reproduced from W. B. Cannon and W. W. Britton) represents cardiac deceleration of the denervated heart of the cat after 1 minute of emotional excitement. Base *B* represents the heart-rate before this stimulation.

(4) (*B*). Curve *A* represents persistence of the accelerator effect after cessation of electrical stimulation of an accelerator nerve. Curve *B* represents persistence of the effect of adrenin and sympathin on the denervated heart after 1 minute of

emotional excitement attended by violent movement. The respective basal rates are represented by broken, horizontal lines. Both of the smooth curves apply to cats, not dogs, but they are presented here for comparison because no similar data are available for dogs. The data from our dog agree well with the theoretical curve of deceleration obtained by combining the two curves *A* and *B*. The only noteworthy divergence is that the tail of the combined curve would be slightly too high relative to the base line for the data from the dog. Whether or not this is a genuine divergence due to the effect of sensitization on the denervated heart of the cat obviously can not be determined until physiological data are available on dogs similar to those of Cannon and Britton and of Rosenblueth and Simeone on cats.[4]

Discussion

The following discussion concerns the interpretation of the persistence of the cardiac response to shots until relief intervenes, and the relation between cardiac response and overt movements. First, however, we must deal briefly with certain temporal features of the cardiac response. In a previous article (**2**) it was suggested that the initial cardiac acceleration in a startled cat is so great that it must be interpreted as due mainly to inhibition of the decelerator nerves—a conclusion consonant with the modern interpretation (**5**) of cardiac acceleration in violent exertion. The same conclusion seems warranted in the case of the dog, particularly since Brouha, Cannon and Dill have shown that a sympathectomized dog manifests cardiac acceleration in both emotion and exercise (**6**). As to deceleration, the data presented above indicate that, in its gross features, cardiac deceleration in the dog is, during the first three minutes, mainly a matter of accelerator after-discharge; thereafter, for some fifteen minutes, it is a matter of the persistence of adrenin and sympathin in the blood. Then when we take into account the evidence of decelerator inhibition in the acceleration elicited

[4] A possible way of dealing with this issue would be to compare with the available physiological data the curves secured from cats after removal of a barking dog.

by the shot, we may add that on these relatively slow changes is superimposed a rapid parasympathetic modulation.

We turn now to the interpretation of the persistence of the reaction to shots until relief intervenes. In his contribution to the Wittenberg symposium, Cannon wrote: "All the main features of the simple reflexes—the inborn, prompt, constant, uniform, permanent, and utilitarian nature of the response to a definite type of stimulus—all these features of the simple reflexes are reproduced in the characteristics of an outburst of rage. . . . The physiological organization which establishes the reflex figure of rage I have detailed because it may serve as a prototype for other primitive emotional responses. The expressions of fear, joy, and grief are similar in character" (7).

What, then, is the stimulus which sets off this reflex-like activity? Rage is " a response to a fairly definite stimulus—an inner stimulus which arises when there is a hampering or checking of motion or an opposition to one or another primary impulse" (7). In other cases the stimulus is apparently thought of as an external object. In Cannon's well-known juxtaposition of diagrams representing the James-Lange theory and his own, the receptor whose activity sets off the neural processes is represented in exactly the same fashion in the two diagrams—indeed, there is a common legend for both. Presumably, then, there is no distinction between the two theories with respect to this receptor. But, Cannon writes: "According to the James-Lange theory an *object* stimulates one or more receptors . . ." (8). No one, surely, would get from such an exposition the notion that the stimulus referred to by Cannon is to be considered in general as an internal one, as an 'impulse' to activity.

The data we have presented indicate that if we are to retain Cannon's general theory, which quite obviously is the best modern theory of the mechanism of visceral expression, his conception of the stimulus in the case of rage must be extended to cover at least the form of fear which we have been dealing with in reactions of our dog to shots. Except for the initial (startle) phase, these reactions are not 'constant' and 'uniform' responses to a definite *external* stimulus. The

reactions persist long after the stimulus has ceased and—more important—this persistence is not invariant, but depends upon the absence of a second stimulus, relief. It is apparent that here, as in the case of rage, we must consider the reactions to be responses to internal factors on the order of directed tensions or impulses.

If what is true of rage is true of fear, it is quite possible that further work will show it to be true of all protracted emotions (émotions-sentiments), as contrasted with startle (émotion-choc). Should this turn out to be the case, we could readily integrate the dynamic doctrines of emotion (McDougall, Lewin and his followers) with the physiological ones. The former would be descriptions of the initial stages giving rise to specific internal stimulation, the latter of the mechanism of expression set off by such stimulation.

The second principal point which we wish to discuss is the relation of visceral changes to skeletal responses. The feature which stands out most prominently throughout our experiment is the marked concomitance of cardiac acceleration and overt movement in emotional reactions. This shows itself in the marked acceleration which occurs when the reaction involves 'jumping with joy,' in the occurrence of a peak in heart-rate at the beginning of the reaction, when there is a marked behavioral readjustment of the animal, and in the circumstance that the high cardiac level after a shot lasts as long as do overt attempts at flight, and ceases with them. Its most striking manifestation, however, is in the marked deceleration which occurs in what is obviously 'fear,' when the animal is cowed by a slap. Here we have support for Dumas' insistence (**9**) that the major emotions may assume a passive form, as exemplified by cardiac deceleration, and also for Kling's (**10**) contention that the picture of emotion as always involving sympathetic excitation has been erroneously arrived at by using only animals which, like cats, are almost wholly aggressive in their reactions.

How is the concomitance of cardiac acceleration and skeletal response in emotional reactions to be interpreted from the point of view of neural mechanisms? It is well known

that muscular exertion is accompanied by cardiac acceleration which begins with the beginning of the exertion (the first beat after the muscular contraction is already shortened, according to Gasser and Meek (**11**)), and which may reach, within a very few seconds, a very high peak (**6**). The occurrence of a sharp initial rise to a peak is favored by the quick onset of the exertion (**12**). We have seen that in the dog this quick increase in heart-rate with exertion may be quite definite even in the case of such minor exertion as change of position. Gasser and Meek (**11**) found that in the human being mere clenching of the fist yielded an increase in heart-rate of 25% within 1.09 seconds of the inception of the movement. It is obvious, therefore, that *to a large extent* our dog's cardiac acceleration to emotional situations can be interpreted as acceleration accompanying exertion—or better, that *to a large extent* his cardiac acceleration in emotion and in exertion can be ascribed to a single neural mechanism common to both types of reaction.

The question arises at once whether this circumstance is peculiar to our experiment, or whether it is true of all emotional reactions. Previous studies show that the rule for emotional reactions is a marked correlation between increase in heart-rate and violence of skeletal response. Cannon and Britton (**4**), for instance, in their experiments on the secretion of adrenin in cats, noted that "The output of adrenin is greatest when emotional excitement is combined with violent struggle." This finding lent support to an hypothesis advanced by them two years earlier according to which "When limitation of the bodily disturbance is desirable, control of the controlable factors, the voluntary muscles, would minimize the effects of an emotional storm." Again, consider the data on emotional reactions of human beings, where skeletal movements are eliminated far more than is possible with animals. The cardiac reaction is so slight, in the case of most stimuli used, that different investigations do not even agree as to whether the typical reaction is acceleration or deceleration (**13, 14, 15**). It seems reasonable, therefore, that the conclusion drawn from our experiments has general validity.

What, now, of those cases of emotional cardiac acceleration which are not correlated with overt movements? A good instance is the report by Brouha, Cannon and Dill (**6**) that dogs, accustomed to being run on a treadmill, may show marked emotional acceleration when the signal for the start of the treadmill is given, although the animals remain motionless. Do such cases show that in addition to the mechanism of acceleration common to emotion and exertion there is a separate, purely emotional, mechanism? Not necessarily. There are two other possibilities: (*a*) skeletal exertion may be present in these cases as tension or trembling, although the animal is 'motionless'; (*b*) skeletal exertion may be present in these cases merely as a central 'set,' prevented through inhibition from manifesting itself in actual movements. A thoroughgoing experimental study of cases of 'motionless emotion' ought to be well worth while. Should it turn out that all or most of the cardiac acceleration could reasonably be interpreted as the concomitant of tensions or motor sets, the modern doctrine of emotion would have to be altered considerably. Either the 'major' emotions would become little more than special cases of violent action (cases where the action is 'impulsive' rather than 'voluntary'), or the present emphasis on visceral changes in major emotions would have to go by the board.

Summary

Study of changes in heart-rate elicited in a gun-shy dog by various forms of emotional stimulation yielded the following facts and conclusions.

(*a*) Initial acceleration caused by shots is so marked that it must probably be ascribed primarily to inhibition of decelerator nerves.

(*b*) The higher above the normal is the level of heart-rate before the shot, the less is the acceleration and the magnitude of rise of heart-rate. There results a marked constancy in the maximal heart rate after shots, in spite of marked differences in initial levels of heart-rate.

(*c*) Acceleration induced by shots or other emotional

stimuli reaches a definite peak during the first 10 seconds after stimulation.

(*d*) In cases where stimulation persists, the initial peak may be followed by other, even higher peaks. The reaction, in such cases, follows the pattern of a tension increasing irregularly to a maximum and decreasing suddenly when there is release from tension.

(*e*) In the case of a shot stimulus, although the stimulus *does not* persist, heart-rate continues at a level little lower than the initial peak for as long as 3 minutes, unless the situation is changed so as to afford relief to the dog. When relief occurs cardiac deceleration promptly sets in. The reaction follows the pattern of a tension induced by a stimulus but continuing in its absence until a new stimulus affords relief. This effect indicates that if the visceral phase of fear responses is to be considered a reflex-like response to a definite stimulus, this stimulus must be thought of as an inner state, akin to a drive to flight. Cannon has already defined the stimulus to anger as an inner state, akin to frustration. The question arises whether the stimulus to any 'émotion-sentiment' is not to be thought of as an inner state, as contrasted to the external stimuli yielding startle.

(*f*) A striking feature of emotional reactions involving cardiac acceleration is the marked correlation between magnitude of heart-rate and violence of overt movements. The initial peak of heart-rate coincides with marked bodily readjustments; subsequent peaks usually correspond to jumping with glee or for food, or to attempts at escape; and a high level of heart-rate, maintained after the beginning of stimulation, corresponds to definite unrest (whimpering, shivering, sudden movements). Conversely, the cowing (fear) produced by a slap corresponds to a marked *drop* in heart-rate. It follows that, to a large extent, the dog's cardiac acceleration in emotion and in exertion can be ascribed to a common neural mechanism. Should this circumstance turn out to be true for emotional reactions in general, either the 'major' emotions would become little more than special cases of violent action (cases where the action is 'impulsive' rather than 'voluntary')

or the present emphasis on visceral changes in 'major' emotions would have to be dropped.

(Manuscript received March 24, 1938)

REFERENCES

1. R. W. MOORE AND W. B. CANNON, The heart rate of unanesthetized normal, vagotomized, and sympathectomized cats as affected by atropine and ergotoxine, *Amer. J. Physiol.*, 1930, **94**, 201–208.
2. J. G. BEEBE-CENTER AND S. S. STEVENS, Cardiac acceleration in emotional situations, *J. Exper. Psychol.*, 1937, **21**, 72–87.
3. A. ROSENBLUETH AND F. A. SIMEONE, The interrelations of vagal and accelerator effects on the cardiac rate, *Amer. J. Physiol.*, 1934, **110**, 42–55.
4. W. B. CANNON AND S. W. BRITTON, Studies on the conditions of activity in endocrine glands, *Amer. J. Physiol.*, 1927, **79**, 433–507.
5. F. A. BAINBRIDGE, *The Physiology of Muscular Exercise*, 3rd ed., rewritten by A. V. Bock and D. B. Dill, London, N. Y., etc., 1931.
6. L. BROUHA, W. B. CANNON AND D. B. DILL, The heart rate of the sympathectomized dog in rest and exercise, *J. Physiol.*, 1936, **87**, 345–359.
7. W. B. CANNON, Neural organization for emotional expression in *Feelings and Emotions, The Wittenberg Symposium*, Worcester, Mass., 1928, 257–269.
8. W. B. CANNON, Again the James-Lange and the thalamic theories of emotion, *Psychol. Rev.*, 1931, **38**, 281–295.
9. G. DUMAS, in *Nouveau Traité de Psychologie*, vol. 2, Paris, 1932.
10. C. KLING, The role of the parasympathetics in emotion, *Psychol. Rev.*, 1933, **40**, 368–380.
11. H. S. GASSER AND W. J. MEEK, The study of the mechanisms by which muscular exercise produces acceleration of the heart, *Amer. J. Physiol.*, 1914, **34**, 48–71.
12. E. C. SCHNEIDER, *Physiology of Muscular Activity*, Phila., 1933.
13. J. G. BEEBE-CENTER, *Pleasantness and Unpleasantness*, N. Y., 1932.
14. L. H. COHEN AND M. PATTERSON, Effect of pain on the heart rate of normal and schizophrenic individuals, *J. Gen. Psychol.*, 1937, **17**, 273–289.
15. H. V. GASKILL, The objective measurement of emotional reactions, *Genet. Psychol. Monogr.*, 1933, **14**, No. 3, 177–281.

EXPERIMENTAL STUDIES OF THE JUDGMENTAL THEORY OF FEELING: II. APPLICATION OF SCALING TO THE MEASUREMENT OF RELATIVELY INDIFFERENT AFFECTIVE VALUES

BY HENRY N. PETERS

University of Missouri

Introduction

In a preceding report on the results of 3 experiments it was found that the pooled affective rank orders of 10 Japanese words could be considerably changed by a learning situation in which the subjects were required to make a positive reaction to 5 of the words and a negative reaction to the other 5.[1] The change wrought by the learning was one of a gain in affective value for each of the 5 words the subject was required to pronounce, with respect to the 5 he was required not to pronounce. The results appeared especially clear in the comparison of the first rankings of the subjects of Experiments 1 and 2, which were made prior to learning or any other experience with the words, and the rankings of the subjects of Experiment 3, which were made for the first time after the learning situation. In the learning problem of Experiment 3 each subject was required to pronounce the 5 words which were ranked on the average lowest in the first rankings of Experiments 1 and 2. The comparison was made in terms of mean rank orders. It is this comparison of pooled rank orders of one group of subjects prior to learning with the pooled rank orders of another group of subjects after learning that is the major concern of this paper. The data of a fourth experiment, an exact duplicate of Experiment 3, are presented;[2] and Thur-

[1] Peters, H. N., Experimental studies of the judgmental theory of feeling: I. Learning of positive and negative reactions as a determinant of affective judgments, J. Exper. Psychol., 1938, **23**, 1–25.

[2] This experiment was assisted by a money grant from the University Research Council, University of Missouri.

stone's absolute scaling technique is applied to the measurement of affective values.

The purpose of Experiment 4 was twofold: (1) to verify the results of Experiment 3, and (2) to increase the number of subjects ranking the words after learning to a size close to that of the number ranking before learning and to a size which would make the use of scaling techniques plausible.

The following are some questions pertinent to the present investigation of the conditions of affective judgments which absolute scaling of the data obtained in Experiments 1–4 should answer. How closely do the results when treated by scaling agree with the treatment by mean rank orders? Which measure, mean or median rank orders, is preferable? Can the assumption made in the preceding paper, that means give approximate scale values, be verified? What influence does the learning situation have on the stimulus dispersions? And lastly, with stimuli of the kind used, is Case III of the law of comparative judgment preferable to Case V?

Experiment 4

The procedure of Experiment 4 was identical in all details with that of Experiment 3.[3] Each subject began by learning to pronounce 5 Japanese words (symbolized in the tables by Roman numerals I to V) every time one of them appeared in the window of a memory drum and not to pronounce the other 5. Immediately after the criterion of 5 perfect trials in succession was reached, the subject proceeded to rank the 10 words in order of preference. Sixty-one subjects, 40 men and 21 women, were used in the experiment.

The mean numbers of trials and errors taken by the subjects to learn the preliminary problem were, respectively, $10.49 \pm .58$ and 27.87 ± 1.81.[4] Table I presents the rank order data for the Japanese words. The first column presents the Japanese words with the Roman numeral symbol of each. In the next 10 columns appear the frequencies with which the

[3] The preceding report contains these details. Mr. Alvin Liberman was the experimenter in Experiment 4.

[4] Unless otherwise stated, all measures of dispersion given herein are in terms of standard deviation.

various words were given the rank orders at the heads of the columns. In the last column are the mean rank orders. The Japanese words are listed from the top to the bottom of column 1 in order of increasing mean rank order, and thus in order of increasing affective value. The Roman numeral symbols were attached to the words on the basis of the means of the composite rank orders of Experiments 1 and 2, numbering in order of increasing means, and thus indicate the relative affective values of the words prior to learning. The composite

TABLE I

THE NUMBER OF TIMES EACH WORD WAS GIVEN EACH RANK IN EXPERIMENT 4 AND THE MEAN RANK ORDER OF EACH WORD

Words	1	2	3	4	5	6	7	8	9	10	M
VIII tatakai	16	7	8	7	7	3	2	2	3	6	4.13
VII karai	8	10	8	10	8	4	7	4	0	2	4.21
I warui	10	5	6	12	5	5	9	5	3	1	4.61
VI kenasu	2	9	11	10	8	8	4	3	3	3	4.75
IX homeru	4	8	6	7	5	10	2	3	9	7	5.57
III tori	2	7	6	3	11	6	4	9	8	5	5.89
II mushi	8	4	4	2	1	8	10	8	8	8	6.15
IV yoi	5	4	4	3	9	5	6	8	10	7	6.20
X amai	6	4	4	1	4	9	5	4	8	16	6.61
V heiwa	0	3	4	6	3	3	12	15	9	6	6.89

mean rank orders for Experiments 1 and 2 may be found in the second column of Table IV.

The mean rank orders of Experiment 4 agree fairly closely with those of Experiment 3. Rank order correlation between the means of the 2 experiments yields a rho of .79. Similarly, the rho obtained from correlating the means of Experiment 3 and Experiment 4, each with the composite means of Experiments 1 and 2, are $-.27$ and $-.07$. The mean number of positive words (I–V) ranked per subject in the 5 most *P* positions (6–10) is, for Experiment 4, $2.92 \pm .12$; and for Experiments 1, 2, and 3, the same figures are $1.85 \pm .10$, $1.95 \pm .12$, and $2.96 \pm .13$. The tendency formerly remarked in the mean rank orders of Experiment 3 for the pleasantness of those words to which the reaction was positive to increase relative to the words to which the reaction was negative is also easily observed in the means of Experiment 4.

Scale Values of the Japanese Words Before and After Learning

For the purpose of calculating scale values for the words, the 121 subjects of Experiments 1 and 2 were treated as one group, the group ranking before learning; and the 131 subjects of Experiments 3 and 4 were treated as the group ranking after learning. From the original rank orders of each group,

TABLE II

Experimental Proportions

Experiments 1 and 2

Words	I	II	III	IV	V	VI	VII	VIII	IX	X
I		.446	.669	.669	.694	.760	.777	.760	.769	.868
II	.554		.620	.595	.694	.719	.736	.711	.835	.835
III	.331	.380		.545	.595	.620	.620	.628	.686	.777
IV	.331	.405	.455		.521	.529	.496	.512	.636	.810
V	.306	.306	.405	.479		.488	.545	.570	.603	.760
VI	.240	.281	.380	.471	.512		.579	.595	.628	.760
VII	.223	.264	.380	.504	.455	.421		.537	.628	.719
VIII	.240	.289	.372	.488	.430	.405	.463		.587	.760
IX	.231	.165	.314	.364	.397	.372	.372	.413		.678
X	.132	.165	.223	.190	.240	.240	.281	.240	.322	

Experiments 3 and 4

Words	VII	VIII	VI	I	IX	II	IV	III	X	V
VII		.489	.565	.588	.618	.611	.672	.718	.748	.771
VIII	.511		.542	.565	.565	.634	.634	.588	.656	.710
VI	.435	.458		.496	.580	.595	.611	.664	.656	.748
I	.412	.435	.504		.519	.618	.649	.695	.580	.756
IX	.382	.435	.420	.481		.565	.580	.634	.603	.687
II	.389	.366	.405	.382	.435		.542	.496	.573	.573
IV	.328	.366	.389	.351	.420	.458		.481	.527	.534
III	.282	.412	.336	.305	.366	.504	.519		.519	.565
X	.252	.344	.344	.420	.397	.427	.473	.481		.466
V	.229	.290	.252	.244	.313	.427	.466	.435	.534	

the frequency with which each word was preferred to every other one was determined by actual count. From these frequencies the proportions of times each word was preferred to every other one were determined. These represent the form of the observed data and are presented for the 2 conditions, before and after learning, in Table II. The sequences in which the words are tabulated in the 2 halves of the table differ; each sequence was arranged on the basis of total number of preferences received. Each percentage given in the

body of the table represents the proportion of times the word at the top was preferred to the word at the side.

Scale values were calculated from these experimental proportions by Thurstone's Case V and Case III methods. The exact methods of calculation are those Thurstone described in his article, 'Stimulus Dispersions in the Method of Constant Stimuli,' *J. Exper. Psychol.*, 1932, **15**, 284–297. According to these methods the zero point of the scale is arbitrarily

TABLE III

SCALE VALUES

Words	Experiments 1 and 2			Experiments 3 and 4		
	Case V	Case III	σ_k	Case V	Case III	σ_k
I.....	−.7456	−.7270	.966	−.2490 (4)	−.1834 (4)	.594
II.....	−.6935	−.7737	1.246	.1223 (6)	.1389 (6)	1.309
III.....	−.2540	−.2602	1.053	.2553 (8)	.2049 (7)	.764
IV.....	−.0823	−.1009	1.065	.2342 (7)	.2821 (8)	1.448
V.....	.0115	.0060	1.017	.4938 (10)	.3561 (9)	.514
VI.....	.0231	.0184	.718	−.2739 (3)	−.2317 (3)	.785
VII.....	.1416	.1221	.807	−.4769 (1)	−.4082 (2)	.778
VIII.....	.1700	.1429	.846	−.3288 (2)	−.4385 (1)	1.699
IX.....	.4548	.4218	.886	−.1051 (5)	−.0901 (5)	.836
X.....	.9745	1.1506	1.385	.3281 (9)	.3699 (10)	1.274

Discrepancies

	Experiments 1 and 2		Experiments 3 and 4	
	Case V	Case III	Case V	Case III
M.....	.026	.022	.026	.017
No. > PE_P.....	18	11	15	8
No. > $2 \cdot PE_P$.....	5	4	5	1

located at the mean of the scale values. In Case V the stimulus dispersions are assumed to be equal and are made the units of the scale. In Case III the stimulus dispersions, as well as the scale values, are calculated in terms of the average stimulus dispersion. The scale values of the 10 Japanese words obtained under the 2 conditions and by the 2 methods of calculation are presented in Table III. In the fourth and seventh columns are the stimulus dispersions for Case III. The sequence in which the words are arranged in column 1 agrees closely with the orders of both sets of scale values for

Experiments 1 and 2. A number in parentheses appears with each scale value calculated for Experiments 3 and 4. These numbers indicate the rank orders of the scale values.

Figure 1 presents graphically the 2 scales calculated by Case III. These scales are drawn with the 2 zero points arbitrarily at the same level. The italicized words are the 5 which were pronounced in the learning situation by the subjects of Experiments 3 and 4 prior to ranking. There are 2 striking contrasts between these 2 scales. One is the difference in the relative positions of the italiziced and non-italicized words in the 2 scales. The relative positions have been nearly inverted in the scale values after learning. This inversion is complete with the exception of the word 'amai' which was of highest affective value in the first scale, and the word 'warui' which had next to the lowest value. Both of these, however, moved in the same direction moved by the other members of the same group of 5 words. The other striking contrast is in the lengths of the 2 scales. The first is more than twice as long as the second, the length of the first being 1.92 σ, that of the latter only 0.81 σ.

This narrowing of the scale after learning indicates that the unit, the average stimulus dispersion, has increased in size approximately 100 percent as compared with the unit of the scale before learning. This does not mean, however, that the subjects' choices approached indifference either because the effects of the learning situation tended to dissipate the affectivity of the words or because the whole experimental situation aroused boredom and therefore hasty judgments. The explanation is rather that the subjects became as a group more heterogeneous in their attitudes toward the words, while at the same time the individual attitudes became more definite than those of subjects ranking before learning. One strong evidence for this explanation is to be found in the subjects' written reports in answer to questions anent their assurance and ease in ranking the words. Of the 61 subjects of Experiment 1, 33 indicated that they had difficulty ranking, 28 that they did not. In Experiments 3 and 4 the corresponding figures were 16 and 54, 17 and 44. The subjects of Experi-

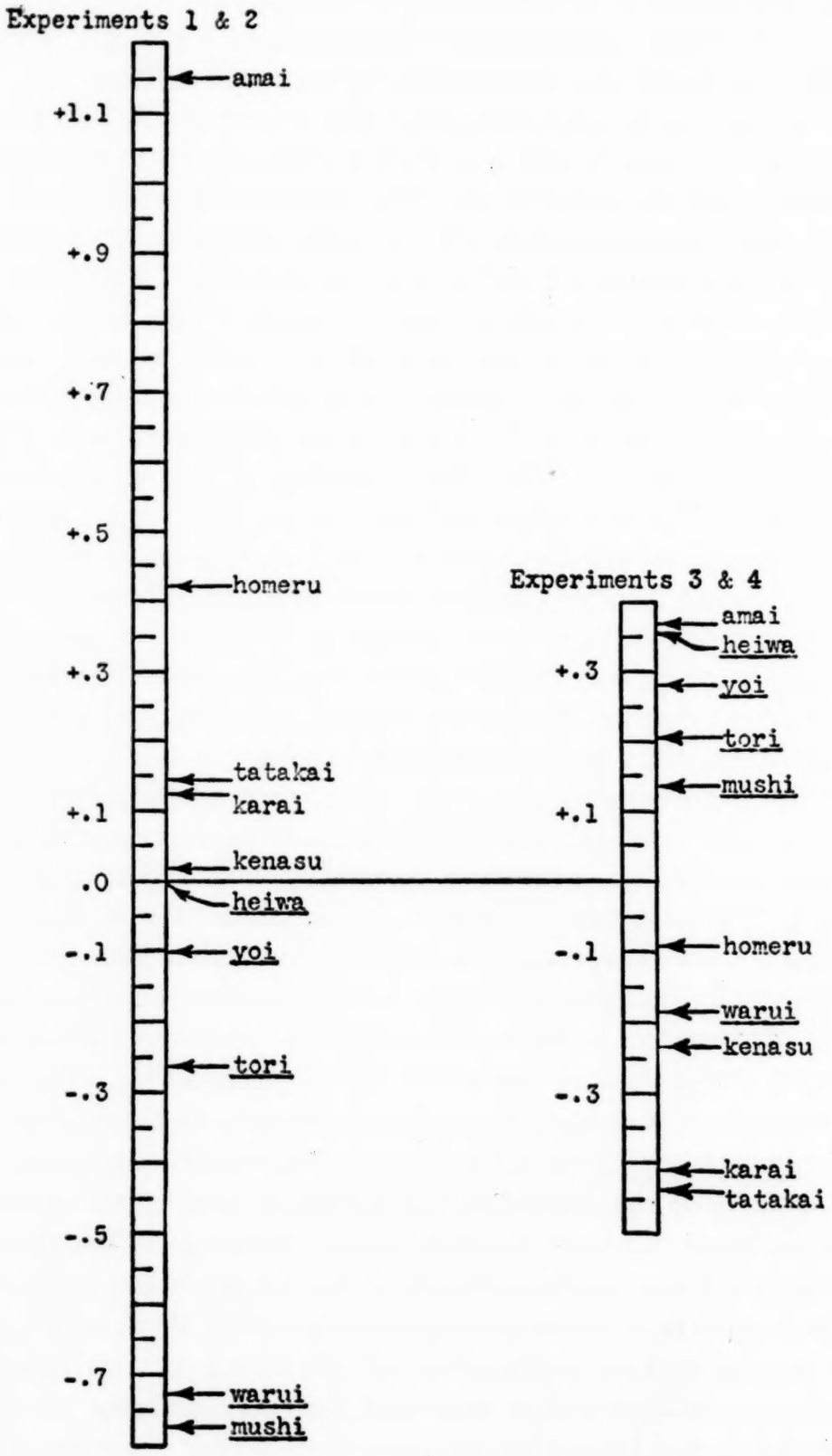


FIG. 1. Scales calculated by Case III, before and after learning.

ment 2 were not required to fill out a questionnaire. To the question "Were you certain of your judgments?" 57 of the subjects of Experiment 3 answered in the affirmative and only 13 in the negative; of the subjects of Experiment 4, 42 answered in the affirmative, 19 in the negative. It is a well-known fact that in human learning experimentation the subjects develop strong affective reactions to materials presented in the window of a memory drum.

Further evidence of the increased stimulus dispersions in the second condition is to be found in correlations of rank orders within each group. Rank order correlation between the mean rank orders of the subjects of Experiment 1 and of Experiment 2 yields a rho of .81; and between the mean rank orders of Experiment 3 and Experiment 4, a rho of .79. When the fact that these correlations are between means is taken into consideration, the slight difference between the 2 coefficients gains some significance. The other correlation coefficients are average intercorrelations of individual rank orders of all subjects in each of the 4 experiments. These coefficients were computed with the aid of Kelley's formula.[5] For the rankings of Experiments 1 and 2 the average intercorrelations are, respectively, .22 and .14. While for Experiments 3 and 4, the corresponding figures are .06 and .10. Both averages for the group ranking after learning are smaller than either average for the group ranking before learning.

An estimate of the extent to which these scale values agree with the mean rank orders, and thus support the conclusions derived from the mean rank orders of Experiments 1–4, may be made by comparing the scale values of Table III with the mean rank orders presented in the second and fourth columns of Table IV. The rank order of the scale values calculated by Case V is identical with the rank order of the means, in both conditions. Neither set of scale values, Case V or Case III, shows any gross variations from the pooled affective ratings in terms of mean rank orders. The scale values calculated by Case III show a few inversions of words having neighboring mean rank orders. The 1 instance of inversion

[5] Kelley, T. L., *Statistical Method*, N. Y., Macmillan, 1923, p. 218.

TABLE IV

MEAN AND MEDIAN RANK ORDERS

Words	Experiments 1 and 2		Experiments 3 and 4	
	M	Mdn.	M	Mdn.
I.....	3.59	3.05	4.83 (4)	4.84
II.....	3.70	2.95	5.84 (6)	6.33
III.....	4.82	4.39	6.19 (8)	6.47
IV.....	5.31	5.46	6.15 (7)	6.75
V.....	5.54	5.79	6.81 (10)	7.39
VI.....	5.55	5.31	4.76 (3)	4.32
VII.....	5.87	6.00	4.22 (1)	3.87
VIII.....	5.97	6.42	4.60 (2)	4.04
IX.....	6.69	7.35	5.21 (5)	5.04
X.....	7.97	8.54	6.40 (9)	6.56

for Experiments 1 and 2 is that of words I and II; for the other condition there are 3 similar inversions: V and X, III and IV, VII and VIII. These inversions may be most readily seen by comparing the scale values by Case III with those by Case V which agree in rank order with the means. If the original treatment of the experimental results had been in terms of scale values, the same conclusions exactly would have been reached.

In the preceding paper the assumption was made that with the kind of objects judged, namely, Japanese words, the distances between different rank orders are all approximately equal. On the basis of this assumption, mean rank orders were used as measures of central tendency instead of the usually recommended median rank orders. The scale values presented in Table III offer an opportunity to test this assumption and also to determine which measure, mean or median, should be used with numbers of subjects too small to warrant scaling. Admitting that scale values give measures of pooled affective value in terms of a constant unit, then mean rank orders may be taken as a similar unit if when scale values are plotted against them the best fitting curve is a straight line of fairly good fit. And if when scale values are plotted against median rank orders, the best fitting curve is either found not to be a straight line or to be a straight line of fit not so good as that for scale values plotted on means,

the means may be taken as a better measure of pooled rank orders than medians.

The 2 sets of scale values for each condition were plotted against both the means and the medians of the same condition (the former presented in Table III, the latter in Table IV), making a total of 8 graphs. The line of best fit appeared in all cases to be a straight line. The parameters and standard errors of estimate of the formulas calculated by the method of least squares are presented in Table V for all 8 plots. The

TABLE V

PARAMETERS AND STANDARD ERRORS OF ESTIMATE OF THE STRAIGHT LINES FIT TO THE PLOTS OF SCALE VALUES ON MEAN AND MEDIAN RANK ORDERS

$Y = a + bX$

Experiments	X	Y	a	b	σ_{yz}
1 and 2.....	M	Case V	−2.140	.389	.009
1 and 2.....	M	Case III	−2.321	.422	.058
1 and 2.....	Mdn.	Case V	−1.580	.286	.073
1 and 2.....	Mdn.	Case III	−1.702	.308	.114
3 and 4.....	M	Case V	−2.040	.371	.004
3 and 4.....	M	Case III	−1.876	.341	.065
3 and 4.....	Mdn.	Case V	−1.407	.253	.057
3 and 4.....	Mdn.	Case III	−1.318	.237	.064

first column presents the condition; the next 2 give the variables, mean or median rank orders (X) and scale values calculated by Case V or by Case III (Y). Columns 4 and 5 show the Y-intercept and the slope of the line. The last column presents the standard error of estimate for each line. With respect to the plot of Case V values on mean rank orders, the goodness of fit is almost perfect. The standard errors of estimate for Case V plotted on medians are for both conditions about 10 times as large. All 4 plots of scale values calculated by Case III on means or medians have standard errors of estimate larger than the corresponding plot for Case V. In the case of Case III values, the goodness of fit is better with the means than the medians for Experiments 1 and 2 and about equal for Experiments 3 and 4.

Since the closeness of fit to scale values is better for mean than for median rank orders in 3 of the 4 comparisons (and is the same in the remaining one), it may be concluded that mean

rank orders give a more valid measure of affective value than do medians. The almost perfect agreement between scale values, Case V, and mean rank orders signifies that with materials such as those used in these experiments and with the assumption that all stimulus dispersions are equal, mean rank orders give affective values in terms of a constant unit. Since the stimulus dispersions, as shown by Case III, are not all equal, the mean rank orders give only rough approximations to absolute scale values. The seriousness of their deviations from absolute scale values, assuming Case III as a standard of comparison, may be roughly appraised by comparing the 2 standard errors of estimate given in the third and seventh rows of Table V with the length of the corresponding scales (refer to Fig. 1). For Experiments 1 and 2 the standard error of estimate is 3/100 of the length of the scale; for Experiments 3 and 4 the standard error of estimate is 8/100 of the length of the scale.

The third from the last row of Table III contains the mean discrepancies between the theoretical and the observed proportions for scale values by both cases. These figures, which test the internal consistency of the scales, are about the same size as those judged 'fairly satisfactory' in studies using twice as many subjects. The seriousness of the discrepancies may be estimated by comparing each discrepancy with the probable error of the experimental proportion. There are 45 such discrepancies for each scale. (Although there are 90 proportions in each table of original and of calculated proportions, the complementary nature of each pair involving the same 2 words makes only 45 comparisons necessary.) In the last 2 rows of Table III appear for each scale the number of discrepancies larger than and twice as large as the PE_p. There were no discrepancies found to be 3 times the PE_p in any scale.

As was to be expected, these figures in the last 3 rows of Table III show greater internal consistency and accuracy for scales computed by Case III than for those by Case V. All 6 figures for Case V are larger than the corresponding ones for Case III. Only economy of effort in calculation could be used as a basis for choosing Case V in preference to Case III. The

relatively high degree of accuracy and internal consistency of both scales is to be accounted for on the basis of the large overlapping of the stimulus dispersions of every pair of stimuli.

Conclusions

The materials presented in this paper constitute tests of the reliability and of the validity of mean rank orders for the type of stimuli involved. Both are found to be satisfactory, at least at the present stage of this investigation of the conditions of affective judgments. The following specific conclusions have been reached:

(1) Experiment 4 duplicates the conditions and the results of Experiment 3. When the mean rank orders for this condition after learning are compared with those for before, the relative positions of positive and negative words are practically inverted.

(2) Scale values calculated by Thurstone's law of comparative judgment verify the conclusions based on mean rank orders.

(3) There is greater heterogeneity of affective attitude after learning than before, which denotes a complex effect of the learning problem.

(4) The assumption that with the stimuli used, mean rank orders approximate scale values is verified.

(5) There is almost perfect agreement between scale values calculated by Case V and mean rank orders.

(6) There is fairly close agreement between scale values calculated by Case III and mean rank orders.

(7) Means agree more closely with scale values than do median rank orders.

(8) Scale values calculated by Case III are more accurate and consistent than are those calculated by Case V.

(Manuscript received March 23, 1938)

THE INFLUENCE OF THE DIFFICULTY OF ACTIVITY ON THE ESTIMATION OF TIME*

BY JOHN J. HARTON

Arizona State Teachers College at Flagstaff

This is a report of three attempts to vary the time judgments of individuals by varying their activities in listening to the beats of a metronome.

I

First it was undertaken to determine just what effect a mere change in rate of beats would have on the individual's estimation of time. There were nineteen undergraduate men students as subjects in this experiment.

Procedure

The subject was first given a norm period of 47 seconds during which he counted the beats of the metronome. The count comes to a hundred at the norm rate of 126 beats per minute in 47 seconds.

When the norm period was closed, the experimenter said:

> This next time the metronome will beat at a slower rate than just now when you counted a hundred beats. Next time count the beats of the metronome until you believe you have counted as long a period of time as it just now required for you to count a hundred. Say 'Now' aloud when you believe you have counted just as long as you counted when you counted a hundred beats. Count silently.

Then the metronome was started. The subject counted to himself and said 'Now' to close the reproduction period. The duration of the period was recorded.

A second norm period was then given under the same conditions as the first.

After a second norm period, like instructions were given for a second reproduction period as for the first with the exception that the subjects were told that the metronome would beat faster while they were counting in the next period. Then a second reproduction period was taken.

The subjects counted to themselves during all periods. The norm rate of 126 beats per minute was chosen, because this rate is counted readily by most individuals.

Time was kept to the nearest second with a standard time watch. Units of less than a second were ignored because they would be without value in these comparisons. Protocols were taken to the question, "How did you determine when to say, 'Now'?"

---

*These investigations were conducted in the laboratories of Duke University during the years 1935 and 1936 as a part of a dissertation for the Ph.D. degree.

The results of this experiment are shown in Table I.

TABLE I

RATES OF BEATS USED AND RESULTS OF REPRODUCTIVE JUDGMENTS OF A NORM OF 47 SECONDS *

Subject	Slow Rate †		Fast Rate †	
	Beats per Minute	No. Seconds Counted	Beats per Minute	No. Seconds Counted
K. D. W.....	104	46	152	47
O. D. H.....	104	32	152	46
M. N.....	104	32	152	59
F. S. B.....	104	37	152	52
W. G. B.....	104	37	152	54
W. S. B.....	104	31	152	48
H. L. P.....	104	35	152	59
A. A. C.....	104	45	152	52
G. M.....	104	45	138	56
D. J. T.....	104	40	152	50
J. G. S.....	104	41	152	59
R. F. M.....	88	55	132	53
B. W. J.....	104	45	152	60
W. M. S.....	104	33	152	61
J. A. D.....	104	32	152	59
R. W. R.....	104	49	152	59
N. F. M.....	104	45	152	48
K. R.....	104	35	152	56
V. L. A.....	104	43	152	52
Average.....		40		54

* The rate during the norm periods was always 126 beats per minute.

† The norm period was presented immediately preceding each reproduction period.

From the table, it can be seen that eighteen of the subjects permitted the metronome to run longer at the fast rate than at the slow rate. One subject gave the reverse result. This proportion is statistically reliable.[1]

$$p = .95; \quad \sigma_p = .05; \quad p - 50 = 9\sigma_p.$$

The average duration for counting the beats at the slow rate is 40 seconds; the average for the fast rate 54 seconds. Thus time as experienced by these individuals passed more rapidly at the fast than at the slow rate.

[1] This statistical treatment makes use of the formula, $\sigma_p = \sqrt{\frac{pq}{N}}$, in which p is one proportion; q, the other. For a proportion to be reliable it is considered that the deviation from a 50–50 proportion should equal three times the standard error of p. The deviation is represented by p minus 50. (Formula from T. L. KELLEY, *Statistical Method*, New York, The Macmillan Co., 1923, p. 90.)

These results agree in general with those of previous investigations. With a rapid metronome, Gulliksen [2] obtained an average estimate of 214.1 seconds for an actual duration of 200 seconds, whereas for the same norm, at a slow rate, the average of the estimates was 223.7 seconds. His estimates were verbal in conventional time units. His results indicate that time passes more rapidly for the individual at the fast rate.

From the protocols, it was learned that seventeen of the subjects used the rate of beats as a basis for reckoning how many to count. All but one of these, however, adjusted their stopping point after they had counted awhile by their feelings as to whether the proper amount of time had passed. Two subjects stated that they did not use the rate of beats at all in determining their judgments of the periods.

Most subjects volunteered that they found it more difficult to count the beats at the fast than at the slow rate.

II

Accepting difficulty as the important variable between these periods, it was decided that it would be a nice test of the hypothesis that periods of time spent at difficult tasks are estimated less than equal periods spent at less difficult tasks, if it could be arranged so that under one set of conditions the fast rate would be more difficult (as above) and under another set of conditions so that the slow rate would be more difficult. This was attempted in the following manner:

One experiment was planned similar to that reported above. It was decided, however, to have the subjects repeat the nonsense rhyme, 'eena meena mina mo,' rather than to have them count the beats. It was thought that this arrangement would prevent the utilization of the rate of beats to determine the close of a period by an arithmetical calculation. It was intended that saying the nonsense rhyme to the beats would be more difficult at the fast rate than at the slow rate.

[2] H. GULLIKSEN, The Influence of Occupation Upon the Perception of Time, *J. Exper. Psychol.*, 1927, **10**, 52–59.

Another experiment was planned in which it was proposed that it would be more difficult to attend to the beats at the slow rate. In this experiment the subjects were told to hear the beats of the metronome in groups of three. Some preliminary trials with several individuals indicated that everyone experienced more difficulty in hearing the metronome beats in groups of three at a rate of 40 beats per minute than they had experienced at rates ranging from 126 to 152 beats per minute.

For convenience in reporting, the first of these two experiments is called the 'Metronome Hearing Experiment;' the second, 'Metronome Rhythm Experiment.'

Metronome Hearing Experiment

In this experiment, the subjects, 33 undergraduate students, were told to listen to the beats of the metronome with their eyes closed, and to say to themselves the rhyme, 'eena meena mina mo,' so that the syllables of the nonsense rhyme would synchronize with the beats of the metronome.

Some demonstration was given and the subjects practiced until they were assured, and also the experimenter was assured, that they understood and could carry out the instructions.

The subjects were instructed not to count the beats, nor the number of times they repeated the rhyme in the norm or reproduction periods, but to depend on just how they felt with regard to the lapse of time in giving their judgments.

In order to prepare them for the fast and slow rates, the subjects were told that the metronome would not beat at the same rate all the time, but to do their best to carry out the instructions to repeat the rhyme to the beats of the metronome during every period of the experiment.

After the experiment began there was a duration of approximately fifteen seconds between the successive periods. Instructions were repeated each time before both norm and reproduction periods to insure that the subject remained oriented.[3]

In Table II, are presented the rates of beats of the norm, fast and slow intervals, and the several orders in which the subjects had their respective trials. From an examination of the table, it may be seen that Norm-fast was used with seventeen subjects, Norm-slow with sixteen.

It would seem that there is a sufficient variation in the order in which the subjects had the trials to insure equaliza-

[3] The procedure with instructions in greater detail is given in Appendix B. John J. Harton. *The Influence of Effort Persistence and Types of Goal Organization on the Estimation of Time.* Unpublished Doctor's Thesis. Duke University Library. Durham, N. C.

TABLE II

RATES OF BEATS AND ORDER OF PERIODS

Subject	Rates of Beats Used			Order of Periods *									
	During Norm Periods	During Reproduction Periods		1 Norm	2 R	3 N	4 R	5 N	6 R	7 N	8 R	9 N	10 R
		Slow	Fast										
1	152	104	208		F		S		F		S		
2	152	104	208		F		S		F		S		
3	126	104	192		F		S		S		F		
4	152	104	208		S		F		F		S		
5	152	104	208		F		S		S		F		
6	152	104	208		F		S		S		F		
7	152	104	208		F		S		S		F		
8	152	104	208		F		S		S		F		
9	152	104	208		F		S		S		F		
10	152	104	208		S		F		F		S		
11	152	104	208		F		S		S		F		
12	152	104	208		F		S		S		F		
13	132	96	176		F		S		S		F		
14	152	104	208		S		S		F		F		S
15	152	104	208		F		S		S		F		
16	152	104	208		S		F		F		S		
17	126	104	200		S		S		F		F		S
18	126	126	208		S		S		F		F		S
19	152	104	208		F		F		S		S		F
20	126	126	184		S		S		F		F		S
21	126	126	208		S		S		F		F		S
22	126	126	208		S		S		F		F		S
23	126	126	208		S		S		F		F		S
24	126	126	208		S		S		F		F		S
25	152	104	208		F		F		S		S		F
26	152	104	208		S		S		F		F		S
27	152	104	208		S		S		F		F		S
28	144	144	208		F		S		S		F		
29	152	104	208		F		S		S		F		
30	152-	104	208		F		S		S		F		
31	126	126	208		S		S		F		F		S
32	126	126	208		S		S		F		F		S
33	126	126	208		S		S		F		F		S

* F—fast.
S—slow.
N—Norm.
R—Reproduction.

tion of what effect any one arrangement of the periods may have tended to produce.

One variation in the order of trials should receive special attention, namely, half of the subjects had five reproduction

periods instead of four. This was done because it became apparent early that no matter whether the reproduction period was at fast or slow beats, the very first reproduction period was likely to be short, and so, in order to favor neither one nor the other outcome, a practice period was introduced. It may be seen that when the order was Norm-slow, in most cases it was Norm-slow, Norm-slow, at the beginning, followed by the other trials Norm-fast, Norm-fast, Norm-slow. The first judgment at the slow rate, then, was counted as practice, and not paired with any at fast rate in considering the results.

When the order of periods began with Norm-fast, there was this factor associated with position working against time seeming less at the fast rate.

It may be noted in Table II, also, that the rates of beats during the norm, fast, and slow periods varied somewhat between respective subjects. One reason for this is that some subjects indicated that they could not keep up with the metronome at all when it ran 208 beats per minute, and so, the fast rate was decreased for them. Also, during the course of the experiment, it was decided to use the norm rate, 126 beats per minute, in both the norm and reproduction periods at slow rates. It was thought that continuing at the same rate in both norm and slow reproduction periods would operate to make the activity during the reproduction period at slow more facile than it would to decrease the rate to 104, as had been done with quite a number of the subjects. In any event, the relation, fast-slow, between the contrasting reproduction periods was maintained throughout the experiment, and, so, it is suggested that these minor changes in the rates of beats are not of primary importance.

After the series of judgments was taken, each subject was asked the following questions: (1) "Which was more difficult to keep up with, the slow beats or the fast beats?" (2) "Did you count or otherwise use any means to determine when you said 'Now'?" Twenty-eight subjects said "Fast" in answer to the first question, five said, "Slow.[4]" Two series

[4] These five who said the slow were more difficult will be referred to especially in the treatment of the results.

of judgments were not allowed to stand. In one case the subject had counted; in the other, she had attempted to visualize the second hand of a watch moving round.

In Table III, there are presented the results obtained in this experiment. The judgments were paired as they occurred in the order of trials as shown in Table II. Any one judgment is thus considered in the results in only one pair. (as has been stated, a norm period preceded each judgment. All judgments were obtained by the method of reproduction.)

Two pairs of judgments are shown in Table III for each subject, together with the ratios that obtain between them. The ratios represent the lesser judgment over the greater in every case. In columns ten and eleven, there is shown the average of the two ratios of each subject.

Table III is read as follows for any subject: Subject 1 permitted the metronome to run 45 seconds at slow rate, 62 seconds at fast rate, as shown in columns two and three. The ratio between these two judgments is .73, as is shown in column four. As shown in columns six and seven, subject 1 permitted the metronome to run 27 seconds at the slow rate, 77 seconds at the fast rate in the other of his two pairs of judgments. The ratio between these judgments as shown in column eight is .35. The average ratio of the judgments of this subject is shown in column ten to be .54.

Before presenting the analysis of these results, it is important that the reader bear in mind that the critical factor in this experiment is degree of difficulty, and that the fast beats were considered the more difficult in setting up this experiment. However, based on the retrospection of the subjects, five of them declared the slow beats to be more difficult. Accordingly, in presenting a summary of Table III proper account will be taken of the subjective feeling of difficulty. The following table IV depicts the outcome of this experiment according to the results of the two pairs of judgments of each individual participating.

Considering all subjects, taking no account of difficulty, sixty-two percent of the judgments are less at fast rates than at slow rates; thirty-eight percent the contrary. But con-

sidering the results on the basis of difficulty corrected by retrospections, there is a much greater difference, namely,

TABLE III

RESULTS OF TIME JUDGMENTS LISTENING TO METRONOME FAST AND SLOW RATES

Subject No.	Length of First Pair of Judgments		Ratios		Length of Second Pair of Judgments		Ratios		Averages of Ratios †	
	No. Sec. at Slow Rate	No. Sec. at Fast Rate	Slow/Fast	Fast/Slow	No. Sec. at Slow Rate	No. Sec. at Fast Rate	Slow/Fast	Fast/Slow	Slow/Fast	Fast/Slow
			Hundredths				Hundredths		Hundredths	
1	2	3	4	5	6	7	8	9	10	11
1	45	62	73		27	77	35		54	
2	32	64	50		41	49	84		67	
3	37	72	51		41	70	59		55	
4	26	45	58		36	51	71		65	
*5	53	49		*92	77	47		*61		*77
6	51	100	51		47	67	70		61	
*7	71	59		*83	52	47		*90		*87
8	80	103	78		66	72	92		85	
9	42	49	86		67	63		94	96	
*10	39	19		*49	45	33		*73		*61
11	39	50	78		41	62	66		72	
12	50	45		90	57	32		56		73
13	36	31		86	35	44	80		97	
14	40	50	80		40	48	83		82	
15	56	45		80	60	50		83		82
16	40	54	74		67	49		73	74	
17	52	25		48	46	27		59		54
18	49	54	91		54	65	83		87	
19	40	83	48		37	66	56		52	
20	70	95	74		86	77		90	92	
21	35	24		69	33	35	94			88
22	44	53	83		39	46	85		84	
23	52	50		96	48	51	94		99	
24	44	41		93	37	48	77		92	
25	45	51	88		40	45	89		89	
26	41	50	82		50	70	71		77	
27	35	62	56		49	64	77		67	
28	62	55		89	40	63	63		87	
*29	52	36		*69	49	33		*67		*68
*30	57	27		*47	57	28		*49		*48
31	43	42		98	44	53	83		93	
32	46	74	62		70	83	84		73	
33	44	48	92		51	53	96		94	

* These subjects found 'slow' more difficult than 'fast.'

† The average of the ratios is merely the arithmetic mean in those cases for which both of the judgments were less for the same one of the two contrasting conditions. In the case of those subjects who gave one judgment less for one condition one time and for the other the other time, one deviation was considered minus; the other, plus, and their sum was divided by two. This quotient (considered the average deviation) was subtracted from 1.00 to yield the average ratio for the subject.

seventy-seven percent of the judgments are smaller for intervals of greater difficulty. This proportion is reliable:

$$\sigma_p = .052; \quad p - 50 = 5\sigma_p.$$

When the two ratios of each individual are averaged as shown in columns ten and eleven of Table III, we find twenty-nine of the thirty-three individuals have ratios indicating smaller judgments of the intervals judged by them as most difficult; four individuals who gave smaller judgments for the easy intervals. The percents for these figures are eighty-eight and twelve respectively. This proportion is reliable:

$$\sigma_p = .057; \quad p - 50 = 7\sigma_p.$$

TABLE IV

RESULTS OF JUDGMENTS HEARING THE METRONOME AT FAST AND SLOW RATES

Type of Subjects According to Difficulty as Determined from Retrospection	Number of Subjects	Number of Instances in Which Time Was Judged Less at Fast Rate Than at Slow Rate	Number of Instances in Which Time Was Judged Less at Slow Rate Than at Fast Rate
Subjects who declared fast rate was more difficult.....	28	41	15
Subjects who declared slow rate was more difficult.....	5	0	10

There would seem to be no valid objection to the classification of these results under the catagories difficult and easy periods on the basis of the subjects' retrospections. The experiment was intended to cause a difference of difficulty between two periods, and if the conditions as set by the experimenter failed to induce the proposed difference for the subject, it would seem a stupid adherence to fail to take this discrepancy between intended and resultant conditions into account.

It seems worth pointing out that those five individuals who declared the slow rate to be more difficult for them, in every case, judged the time to be less at the slow rate. They also gave reasons why it seemed more difficult for them to keep up with the beats at the slow rate. The reasons given by subjects are: (5) "I have to hold back for the slow beats." (29) "As a child, I said this rhyme a great deal. Then I said it

fast. Now, I find it harder to say it slowly." (3) "I believe the slow are more difficult because you have to kinda wait on them." (10) No reason. (7) Same as (5).

It is possible that these five subjects attempted a more definite organization of the beats and found it more difficult at the slow rate. The other subjects merely kept up with the beats and found it more difficult at the fast rate. If it was an attempt to pattern the beats, as their replies indicate, the results of the judgments of this group of five subjects correlate perfectly with the results of the metronome rhythm experiment which is reported in a succeeding section of this report.

In one respect the results obtained from the five individuals who found the slow rate more difficult may be more significant than the results of the other twenty-eight because they were definitely certain which was more difficult for them, whereas some of the other may have answered 'fast' without as thorough reflection.

Comparison of Relations between Difficult-Easy Judgments with Relations between Judgments of Like Periods

Since the arrangement of the order of judgments at fast and slow rates necessitated the occurrence of judgments of periods at like rates in succession, there is provided another control in the experiment besides the number of lesser judgments at the fast rate.

There were seventy-two instances in this experiment that there were judgments of like periods in succession (*i.e.*, reproduction at slow followed by reproduction at slow and reproduction at fast followed by reproduction at fast). Taking the order of occurrence as the criterion we find the following relationships: Period occurring first judged less than second in forty-two comparisons; equal in one; greater than in twenty-nine. The proportion of first less than second = .59; σ_p = .058; $p - 50 = 1.6\sigma_p$. This is not reliable. As shown above with difficulty as the criterion, $p - 50$ is equal to $5\sigma_p$ where position was controlled by alternating the order of difficult and easy periods.

Also, the ratios of these pairs of judgments of like periods were calculated and the average of all of them, lesser divided by the greater each time, was found equal to .83. The average of the fifty-one ratios, difficult to easy, equals .73. The difference between these means is statistically reliable. $\sigma_{diff.\ means} = 2.6$; diff. means $= 3.8\sigma_{diff.\ means}$.

From these findings, it is shown that there was a variable between the difficult and easy periods of sufficient degree to make a difference in judgments between those periods reliably greater than the differences produced by chance factors between periods of like activity.

Average Judgments of the Contrasting Periods

The average of all the judgments at difficult rate is 56.2 seconds; at the easy rate, 45.5 seconds.

On the basis of the analyses made: using the number of paired intervals; or the individual as the unit; or on the basis of the averages of the judgments; it is shown in this experiment that time is judged less that is spent at relatively more difficult activity.

III

The Metronome Rhythm Experiment Procedure [5]

This experiment in reproduction of time periods while hearing the metronome in groups of three beats was conducted during the second visits of these subjects who served in the preceding experiment.

Very much the same procedure was followed as in the metronome hearing experiment. The subjects were instructed in the procedure and given some training and practice in hearing the metronome in groups of three beats to be certain they could follow instructions and also to make sure just what was the optimum rate for each one to hear the metronome in groups of three beats. This optimum rate was then used in both the norm intervals and in the intervals reproduced with the metronome beating fast. The metronome beat forty

[5] The procedure with instruction in detail is presented in Appendix C. J. J. Harton, *op. cit.*

times per minute during all periods of reproduction at the slow rate.

In Table V are shown the orders of judgments and the

TABLE V

RATES OF BEATS AND ORDER OF JUDGMENTS

Rates of Beats				Order of Judgments									
Subject	Norm	Fast	Slow	Norm	1 Reproduction	Norm	2 Reproduction	Norm	3 Reproduction	Norm	4 Reproduction	Norm	5 Reproduction
1	126	152	*40		F		S		F		S		F
†2	152	152			S		F		F		S		F
3	126	126			S		S		F		F		S
4	152	152			F		F		S		S		F
5	152	126			F		F		S		S		F
6	152	152			F		F		S		S		F
7	126	126			F		S		S		F		F
8	126	126			F		S		S		F		F
9	126	126			F		F		S		S		F
10	126	126			F		F		S		S		F
11	152	152			F		S		S		F		F
12	152	152			F		S		S		F		F
13	126	126			F		F		S		S		F
14	126	126			F		F		S		S		F
15	126	126			F		F		S		S		F
16	126	126			F		F		S		S		F
17	126	126			F		F		S		S		F
18	126	126			F		F		S		S		F
19	126	126			F		F		S		S		F
20	126	126			F		F		S		S		F
21	126	126			F		F		S		S		F
22	126	126			F		F		S		S		F
23	126	126			F		F		S		S		F
24	126	126			F		F		S		S		F
25	126	126			F		F		S		S		F
26	126	126			F		F		S		S		F
27	126	126			F		F		S		S		F
28	126	126			F		F		S		S		F
29	126	126			F		F		S		S		F
30	126	126			F		F		S		S		F
31	126	126			F		F		S		S		F
32	126	126			F		F		S		S		F
33	126	126			F		F		S		S		F

* This rate was the same for all subjects.

† This was the only subject who after the series stated that the rhythm of 3 was more difficult to hear at the fast then at the slow beats.

rates of beats of the metronome used for each subject in the norm and reproduction periods. Every subject had the rate of forty beats per minute during the reproduction periods at

the slow rate. One subject had the order: norm-slow, norm-fast, norm-fast, norm-slow. One subject had the order: norm-fast, norm-slow, norm-fast, norm-slow. One subject had the order: norm-slow, norm-slow, norm-fast, norm-fast, norm-slow. Five subjects had the order: norm-fast, norm-slow, norm-slow, norm-fast. Three subjects had the order: norm-slow, norm-slow, norm-fast, norm-fast. Twenty-two subjects had the order: norm-fast, norm-fast, norm-slow, norm-slow, norm-fast.

There were several reasons for the adoption of the same order of reproduction periods for the majority of the subjects. In the first place, it was considered desirable to enhance the facility with which the subjects heard the metronome beats in groups of three at the optimum rate. Secondly, it was desired to make the contrast between hearing the beats at the optimum and at the slow rate as great as possible. The order adopted for twenty-two subjects seemed to accomplish these purposes.

Furthermore, it was considered, at the time, an adequate control of position of reproduction periods to have one pair when fast preceded slow and one pair the reverse. However, had the experiment been conducted after it was learned that there were some factors associated with position, it would have been desirable to have introduced greater variation in the order of these reproduction periods. Even so, there were some variations in the orders, enough, it is suggested, to afford some controls, and, of still greater importance *the very first reproduction period was not paired with any other one*, and, so, the chief factor in position was controlled in the same manner as in the preceding experiment.

The results of these time judgments are presented in Table VI.

From a study of the table it may be seen that of sixty-six pairs of judgments the period at the slow rate was judged less than the period at the fast rate sixty times, equal to it one time, greater than five times.

This proportion is reliable: $p = .91\ \sigma_p = .035$; $p - 50 = 11\sigma_p$.

TABLE VI

RESULTS OF TIME JUDGMENTS HEARING METRONOME IN GROUPS OF THREE BEATS AT FAST AND SLOW RATE

Subject No.	First Pair of Judgments		Ratios		Second Pair of Judgments		Ratios		Averages of Ratios	
	No. Sec. at Fast Rate	No. Sec. at Slow Rate	Fast/Slow	Slow/Fast	No. Sec. at Fast Rate	No. Sec. at Slow Rate	Fast/Slow	Slow/Fast	Fast/Slow	Slow/Fast
			Hundredths				Hundredths		Hundredths	
1	2	3	4	5	6	7	8	9	10	11
1	40	53	75		33	53	62		69	
2	36	65	55		60	66	91		73	
3	54	94	56		64	73	88		72	
4	32	42	76		30	51	59		68	
5	52	75	69		48	57	84		77	
6	49	66	74		51	59	86		80	
7	47	64	73		49	60	82		78	
8	53	55	96		53	62	85		91	
9	53	70	76		52	95	55		66	
10	33	46	72		33	45	73		73	
11	36	76	47		35	86	41		44	
12	21	50	42		25	54	46		44	
13	38	44	86		40	74	54		70	
14	46	55	84		47	57	82		83	
15	48	62	77		48	76	63		70	
16	52	54	96		40	58	69		83	
17	39	51	76		43	52	83		80	
18	61	84	73		62	101	61		67	
19	69	92	75		49	61	80		78	
20	53	77	69		35	60	58		64	
21	40	50	80		42	52	81		81	
22	29	57	51		40	54	74		63	
23	49	73	67		48	72	67		67	
24	57	60	95		44	53	83		89	
25	35	40	88		40	43	93		91	
26	39	43	91		45	40		89		99
27	49	73	67		49	60	82		75	
28	66	66		100	73	81	90		95	
29	38	70	54		43	44	98		71	
30	36	46	78		34	47	72		75	
31	49	45		92	44	64	69		88	
32	55	46		84	40	58	69		92	
33	75	53		71	49	40		82		77
No. cases			29	4			31	2	31	2
Averages all cases					46	61	73	84		

Comparison of Relations between Difficult-Easy Judgments with Relations between Judgments of Like Periods

There were sixty-nine instances in this experiment that judgments of like periods came in succession (*i.e.*, reproduction at fast followed by reproduction at fast; by slow followed slow). Comparing the first with the second in each of these pairs of judgments of like periods, there are thirty-six instances when the first was less than the second; two, equal; and thirty-one when the first was the greater of the two. This proportion of firsts less than seconds is: .54; $\sigma_p = .06$; $p - 50 = .7\sigma_p$. Thus, the proportion is not reliable. As shown above, with difficulty as the criterion, $p - 50$ is equal to $11\sigma_p$ where position was controlled by alternating the order of difficult and easy periods.

The average of the ratios of these pairs of judgments of like periods, the lesser divided by the greater, is .86. As shown in Table IV, column eight, the average of all the ratios difficult to easy is .73. The difference between these means is statistically reliable: $\sigma_{diff.}$ means = 2.3; diff. means = $5.7\sigma_{diff.}$

It is shown by these findings that there was a variable between these difficult and easy periods that operated to produce reliably greater differences between the two contrasting periods than chance factors produced between the like periods.

Average Judgments of the Contrasting Periods

As shown in columns six and seven, Table VI, the period with fast rate was reproduced, on the average, 46 seconds; the slow, 61 seconds.

It is shown by the above findings that time seemed less to these individuals at the slow beats of the metronome. The activity at the slow rate was declared the more difficult by the subjects.

These results, therefore, are in conformity with the results of the preceding experiment, when the variable between the periods is considered to be the degree of difficulty in the ac-

tivities during the periods. The results are directly contrary if the rate of beats of the metronome is taken as the variable.

Repetition of Metronome Activities with Groups

It was considered desirable to attempt the metronome experiments with subjects in groups. The method of securing judgments was changed from reproduction to verbal estimates in seconds. As in the individual experiments the subjects were asked to designate the difficult activity of each pair. The retrospections concurred with the intended difficult and easy activities, and accordingly these results are presented in Table VII, according to the categories, difficult and easy.

TABLE VII

Results of Metronome Experiments with Groups

Experiment	Result of Estimates		
	Diff. < Easy	Diff. = Easy	Diff. > Easy
(1) Metronome Hearing.....	47	5	26
(2) Metronome Rhythm.....	27	5	10

The proportion, Diff. < Easy of the metronome hearing judgments (with half the Equals added to the dichotomous judgments),[6] is .64; $\sigma_p = .055$; $p - 50 = 2.5\sigma_p$.

The proportion Diff. < Easy of the metronome rhythm judgments (as above) is .71; $\sigma_p = .07$; $p - 50 = 3\sigma_p$.

It is apparent that there are wide differences between the reliabilities of these proportions of judgments in the metronome experiments and those obtained in the laboratory experiments with individuals. It is suggested that foremost of the causes for the differences is in the method of securing judgments. Instead of reproducing the norm periods under the contrasting conditions, the subjects estimated in minutes and seconds the periods of contrasting conditions immediately after each was presented. The periods were presented in

[6] In order to utilize the equal estimates made on periods spent at different activities, it was considered desirable to divide them equally and add one-half to each of the contrasting results.

varying sequences. In the laboratory trials the variable was effective during the period of judging; in the group experiments, the variable was effective only in retrospect.

It is worth adding that the averages of the group estimates of the periods spent in listening to the metronome bear out clearly the trends of the earlier experiments. This is shown in Table VIII.

TABLE VIII

COMPARISON OF GROUP ESTIMATES WITH INDIVIDUAL REPRODUCTIONS

Activities	Averages of Estimates and Reproductions		
	Reproduced by Individuals	Estimated by Groups	Actual Time
	Seconds	Seconds	Seconds
Hearing Fast Metronome Beats.....	56.2	47	47
Hearing Slow Metronome Beats.....	45.5	51	47
Grouping Fast Metronome Beats.....	46	46	47
Grouping Slow Metronome Beats.....	61	40	47

The significant result shown in Table VIII is the consistency with which the lesser of the estimates of two contrasting periods parallels the greater reproduction period, and vice versa. For the results to be consistent, this is as it should be.

CONCLUSION

From the results of these experiments, it seems evident that the rate of beats at which a metronome runs is not the determining factor in the judgments of time during such periods, but rather the activity of the individual who is listening to the beats.

It has been found that if individuals merely keep up with the beats of the metronome by counting or repeating syllables to synchronize with the beats, time seems to pass more rapidly at the *fast* than at the slow rate. But if the individuals are grouping the beats into specific patterns, it is found that time seems to pass more rapidly at the *slow* than at the fast rate.

In both cases, in conformity with the intended objective conditions corrected by the retrospection of the individuals, time passes more rapidly at the more difficult activity.

In the case of these experiments, it should be noted, the tasks were not of such difficulty that the individuals failed to

perform them. The author suggests that this condition is of prime importance. Had the difficult tasks been too difficult for performance, the results would probably be less clear-cut, if not ambiguous. Other factors, such as feelings of success or failure, strain, stress, and the like, would in great probability play an important role in the judgment of time.

(Manuscript received April 21, 1938)

RETROACTIVE INHIBITION: SERIAL VERSUS RANDOM ORDER OF PRESENTATION OF MATERIAL

BY E. DONALD SISSON

Louisiana State University

Most studies of retroactive inhibition in recent years have added to the growing weight of evidence favoring an explanation of the phenomenon in terms of transfer.[1] This evidence consists mainly in the finding that retroaction increases with the *similarity* between the original and interpolated tasks. The factor of similarity may lie in any one or more of several dimensions of the tasks, *e.g.*, operation, content, meaning, temporal and spatial factors, degree of organization, environmental conditions, etcetera. In a previous paper by the author,[2] it was found that retroaction also varied as the degree of associative value of the original and interpolated materials. In this case, nonsense syllable lists were used of one hundred and zero percent associative value, and retroaction was found to be greatest where the two tasks were of the same degree of associative value. An explanation was suggested in terms of isolation of the underlying central organizations or memorial substrates of these tasks in the case of materials of widely different associative values. Such isolation would lessen the chances for inter-list confusion at the time of recall.

The present experiment was designed as a further test of this hypothesis. It was assumed that serial presentation of material would result in a more coherent, closely intra-associated memorial cluster than would result from a random

[1] For summaries of the literature on retroactive inhibition the reader is referred to Britt, S. H., Retroactive inhibition: a review of the literature. *Psychol. Bull.*, 1935, **32**, 381–440; McGeoch, J. A., Learning and retention of verbal material. *Psychol. Bull.*, 1934, **31**, 381–407. For a discussion of the major theories of retroactive inhibition see Britt, S. H., Theories of retroactive inhibition. *Psychol. Rev.*, 1936, **43**, 207–216.

[2] Sisson, E. D., Retroactive inhibition: the influence of degree of associative value of original and interpolated lists. *J. Exper. Psychol.* (in press).

order of presentation. Then, according to the hypothesis, the latter condition should result in a larger amount of retroaction.

Procedure

The experiment involved the learning and recall of 10 two-syllable adjectives. Two methods of presentation were employed: (1) serial order, in which the 10 words were presented 5 times each, always in the same serial order, and (2) random order, in which the 10 words were given 5 times each, but in a random or jumbled order. The words were typed on long lists (50 items) and presented by an electrically driven memory drum at the rate of 2 seconds per word. Learning was by the method of retained members. The subject attended to the words for one complete circuit of the list (5 presentations of each word). He was then asked to write down as many of the words as he could. 90 seconds were allowed for this. 10 minutes later he was again required to write down as many of the words as he could recall, another 90 seconds being allowed for this delayed recall.

In the rest conditions, the subject spent the 10-minute interval between immediate and delayed recall in reading jokes and selecting the best of those read. In the work conditions, a second list of the same kind was presented immediately. The remainder of the 10-minute interval, from immediate recall of this interpolated list to delayed recall of the original list, was filled with reading and selecting jokes as under the rest conditions. Immediately following delayed recall of the original list, delayed recall of the interpolated list was obtained.

Four conditions were studied: rest and work with serial order of presentation, and rest and work with random order of presentation. The subjects went through these four conditions in a counterbalanced order to avoid practice and specific list effects. 18 subjects were studied. All of these were freshmen, and none had had any exposure to psychology.

Results

The mean numbers of words written by the subjects during immediate recall under the various conditions studied are given in Table I. These values are in fairly close agreement, differences between them being statistically insignificant.[3] It

TABLE I

Mean Number of Words Written During Immediate Recall ($N = 18$)

	Condition	Original		Interpolated	
		Mean	σ_m	Mean	σ_m
Serial Order.....	Rest	7.50	.28		
	Work	8.39	.27	7.11	.50
Jumbled Order.....	Rest	7.44	.38		
	Work	7.83	.29	7.11	.38

[3] The difference between the rest and work condition under serial presentation is .89 with a standard error of .39 (C.R. = 2.28). The same difference under jumbled order is .39 with a standard error of .48 (C.R. = .81).

is, perhaps, somewhat surprising that the serial order of presentation shows no clear advantage over the jumbled order, although there may be a hint of such advantage. The fact that the values for the interpolated lists are low in each case is probable evidence of negative transfer.

The mean numbers of words recalled after rest and work are presented in the second table. These figures reveal, first, that the lists learned with the jumbled order of presentation are retained somewhat better after rest than those learned with the serial order. This fact is more striking if it is remembered that the latter condition showed a slight advantage under learning. In terms of percentages the figures are: serial

TABLE II

MEAN NUMBER OF WORDS WRITTEN DURING DELAYED RECALL ($N = 18$)

	Condition	Original		Interpolated	
		Mean	σ_m	Mean	σ_m
Serial Order.....	Rest	5.17	.36		
	Work	3.11	.50	4.30	.58
Jumbled Order.....	Rest	5.86	.58		
	Work	2.78	.46	3.92	.47

order—68.93 percent of the words learned under the rest condition are retained; jumbled order—78.76 percent. The explanation for the difference, if it is a true difference, may lie in the fact that more stable and more meaningful associations are formed between the terms of the jumbled-order lists, whereas the serial learning may be largely rote. This suggestion was confirmed by the unsolicited remarks of one subject who commented on the different methods employed in learning the two kinds of material.

Table II also shows that the mean number of words recalled of the work lists is somewhat less under the condition of jumbled order of presentation than of serial order. The differences are not large and are not statistically reliable, but both differences (original and interpolated lists) are in the same direction.

Percentages of retroactive inhibition were computed ac-

cording to the formula: the difference between percentage of recall under work and under rest divided by the percentage of recall under rest.

$$\text{Percent R.I.} = \frac{\text{Percent } R_R - \text{Percent } R_W}{\text{Percent } R_R}.$$

This formula allows for the slight differences that occur in the means at immediate recall.[4] The values computed by this formula are given in Table III. In each case, the jumbled order of presentation resulted in a larger percentage of retroactive inhibition than the serial order. The values for the interpolated lists are smaller than those for the original lists for two reasons: (1) a shorter time had elapsed since learning,

TABLE III

PERCENTAGES OF RETROACTIVE INHIBITION ($N = 18$)

	Orignal Lists	Interpolated Lists
Serial Order	46.22	12.26
Jumbled Order	54.93	30.00

and (2) there is opportunity for rehearsal during the recall of the original list.

Overt Transfer.—The written records were examined for instances of overt transfer. This means the incorrect inclusion in one list of a word which is correct for another list learned at the same sitting. There are three categories of such transfer: (1) a word which is correct for the original list is recalled in the immediate recall of the interpolated list; (2) a word which is correct for the original list appears in the delayed recall of the interpolated list; and (3) an item from the interpolated list is recalled as part of the delayed recall of the original list. The number of such cases and the number of subjects exhibiting such overt transfer are tabulated below for each of the conditions of learning.

Overt transfer occurs in both directions,[5] and in all three

[4] This formula is used by Foran, J. G., Retroactive inhibition in relation to age and the nature of the interpolated task. *J. Educ. Psychol.*, 1937, **28**, 451–460, and by others.

[5] The reader is referred to McKinney, Fred, and McGeoch, J. A. The character and extent of transfer in retroactive inhibition: disparate serial lists. *Amer. J. Psychol.*, 1935, **47**, 409–423.

categories. There is very little of such transfer from original list to immediate recall of the interpolated list. Most of the overt transfer is found at the time of delayed recall—of either the original or interpolated list. Therefore, most of the overt transfer would account for inhibition of the reproductive type.[6]

In the interest of the present study, it should be pointed out that overt transfer, especially at the time of delayed recall, is more prevalent in the jumbled than in the serial order of presentation. This is true with regard to both the number of words and the number of subjects. If the last two rows of Table IV are considered together, since both represent transfer

TABLE IV

Overt Inter-List Transfers

Direction of Transfer	Serial Order			Jumbled Order		
	Words	Subjects	%S's	Words	Subjects	% S's
Original to Interpolated						
At Initial Recall	1	1	5.6	2	2	11.1
At Delayed Recall	9	6	33.3	12	10	55.6
Interpolated to Original	13	9	50.0	20	8	44.5

at the time of recall, it will be seen that there were 22 words recalled in wrong lists under conditions of serial presentation and 32 words under the random order. The comparable figures for number of subjects are 12 and 13. This last difference is probably negligible, but the average number of overt transfers made by these subjects are 1.83 and 2.46 respectively. It seems safe to conclude that, within the limits of this experiment, there is more overt transfer of the reproductive sort with an unordered presentation of material than with an ordered method.

Discussion

The purpose of this experiment, as stated in the beginning of the paper, was to test the hypothesis that retroaction occurs

[6] For a discussion of reproductive inhibition see McGeoch, J. A., McKinney, Fred, and Peters, H. N., Studies in retroactive inhibition: IX. Retroactive inhibition, reproductive inhibition and reminiscence. *J. Exper. Psychol.*, 1937, **20**, 131–143.

because of confusion at the time of recall between the memorial organizations of two learned tasks. It was assumed that serial presentation would foster the formation of associative linkages between adjacent (and to some extent, more remote) items of the list, whereas such linkages would be absent in the lists presented in a jumbled order. In the latter case, learning would necessitate the formation of associative bonds between the members of the list and other parts of the subject's total memorial organization, including those parts representing other recently learned items. If this is true, the serially presented lists would be represented in the central organization by a more coherently intra-associated and insulated memorial substrate than would be true for the lists presented in random order. Thus, at the time of recall, there would be more tendencies to recall items from the wrong list, or to be blocked altogether, in the case of random presentation than in that of serial presentation. This situation appears to obtain in the present experiment. It has been shown that there was both more retroactive inhibition and more evidence of overt transfer at the time of recall under this condition of jumbled presentation.[7]

It is worth noting that these results also corroborate the evidence on the inefficacy of similarity in serial position in producing marked amounts of retroactive inhibition.[8] Serial position, as a factor in producing retroaction, should have been operative under the condition of serial presentation of

[7] McGeoch and McKinney, Studies in retroactive inhibition: VII. The influence of the relative order of presentation of original and interpolated paired associates. *J. Exper. Psychol.*, 1937, **20**, 60–83, presented paired associates in serial and changing orders, with the usual experimental conditions for retroactive inhibition. They found more retroaction when both original and interpolated tasks were presented in the serial order. This can be explained by the suggested hypothesis if we make the reasonable assumption that serial presentation of paired associates would foster associative bonds between the various members of the serial list as well as between the members of the pair, and that such extra or outside associations would be weakened by the technique of changing the order of presentation.

[8] See McGeoch, J. A., and McGeoch, G. O., Studies in retroactive inhibition: VI. The influence of relative serial positions of interpolated synonyms. *J. Exper. Psychol.*, 1936, **19**, 1–23; and McGeoch, J. A., and Sisson, E. D., Studies in retroactive inhibition: XI. The influence of the relative serial positions of interpolated synonyms in twenty-item lists. *J. Exper. Psychol.* (in press).

the material. It may have worked to diminish the apparent size of the difference between the two conditions in retroaction. The present experiment, unfortunately, affords no evidence on this point.

Summary

18 subjects went through two rest and two work conditions in a counterbalanced practice order. One rest and one work condition were with serially presented lists. The others were with lists presented in a jumbled order. Learning was by the method of retained members.

1. A greater percentage of retroactive inhibition resulted from the jumbled order of presentation.

2. There was a somewhat larger number of overt transfers from one list to the delayed recall of another under the condition of jumbled order of presentation.

3. An hypothesis has been suggested to account for these results.

(Manuscript received March 24, 1938)

THE EFFECT OF VARYING THE POSITION OF THE HEAD ON VOLUNTARY RESPONSE TO VESTIBULAR STIMULATION*

BY ROLAND C. TRAVIS

Western Reserve University

General Introduction

In the experimental studies by Dodge (1), Travis and Dodge (2), Travis (3) and Gurnee (4) of vestibular sensitivity and the perception of passive motion of the body the position of the head of the subject remained approximately constant with the eye-ear axis in the horizontal plane. As far as the knowledge of the author is concerned a systematic report on the effect of varying the position of the head in the voluntary response to the perception of motion has never been made. The present report bears directly on this particular problem, that is, what effect does systematically varying the position of the head have on voluntary response to vestibular stimulation?

The problem of determining the exact function and relative sensitivity of the semicircular canals, the utricle and saccule of the internal ear is extremely difficult because of the intimate connection between the vestibular system as a whole and the proprioceptors in the muscles. The unanimity of function of these two types of sensory patterns is apparent in the reflex adjustments of the voluntary muscles in establishing and maintaining bodily equilibrium. It is impossible, introspectively, to differentiate between vestibular and proprioceptive stimulation. The conscious localization of vestibular sensations is further complicated by the reflex connection between the static sense and the ocular muscles. A previous study (3) by the author threw light on the antagonistic and reinforcing influences of the vestibular system on ocular behavior under various experimental conditions. Among other

* Grateful acknowledgment is extended to Robert Nuss and Joseph Votypka for their assistance in this study.

important differences the latency of eye movements was greatly increased when vestibular stimulation was antagonistic to ocular stimulation and conversely the latency of eye movements was greatly decreased when vestibular stimulation was in harmony with ocular stimulation. During that study and in an earlier one (**2**) attempts were made to localize consciously the source of the sensory information in the perception of passive bodily motion. The most common introspection during passive oscillation with the subject blindfolded and his body restricted was the sensing of a slight pressure in the head just back of the eyes. These introspections suggest that reflex proprioceptive stimulation of the external muscles of the eye is responsible for the conscious accompaniments of the perception of rotary oscillation of the body. Under the rigidly controlled conditions of the intensive study (**2**) made by Dodge and the author, little doubt remains that vestibular stimulation plays an important part in the perception of passive bodily motion however futile the task of its conscious localization may be.

According to Kopetzky in his *Otologic Surgery* (**5**) when the head is erect the horizontal canals are not parallel to the floor and in order to make them parallel to the base line the head must be inclined forward 30 degrees. The vertical canals, both superior and posterior, are perpendicular to the plane of the horizontal canals. This author states further that by inclining the head 120 degrees forward or 60 degrees backward both the superior and posterior vertical canals are placed in a horizontal position for maximum stimulation by the rotation chair. Kopetzky seemed to overlook the fact that the superior and posterior vertical canals are in two different planes and approximately at right angles to each other. Thus in order to bring either one in the horizontal plane the head must be not only inclined backward but also to one side.

In order to determine experimentally the position of the head which would be most effective in voluntary response to perceived passive motion of the body three different positions were employed, namely, eye-ear axis on the horizontal, eye-ear

axis 45 degrees head inclined backward and eye-ear axis 45 degrees head inclined forward. The sagittal plane of the head remained in the vertical plane. These three positions used do not correspond to the positions recommended by Kopetzky for maximum stimulation of each set of canals. However, the factors of comfort and muscular tension in severe contortion of the neck of the subject are of considerable importance in obtaining reliable voluntary responses.

Apparatus and Procedure

A modification of the Dodge rotation platform mounted on a cone and ball-bearing base served to produce controlled vestibular stimulation. A heavy chair was mounted on the platform so that the axis of rotation ran approximately between the right and the left vestibular mechanism when the subject was seated in the chair with the head supported in the head-rest in the upright position. The angular position of the head could be varied over 90 degrees in the sagittal plane by adjusting the head-rest.

The platform was rotated in the horizontal plane through 2 degrees by an offset attachment to an eccentric on a pulley which was rotated through a reducing pulley by an electric motor. This type of oscillation approximates sine-wave or harmonic motion with two phases of acceleration and two phases of deceleration in each complete oscillation. The driving rod was attached 100 cm from the axis of rotation to provide sufficient leverage and smoothness in oscillating the platform and the subject.

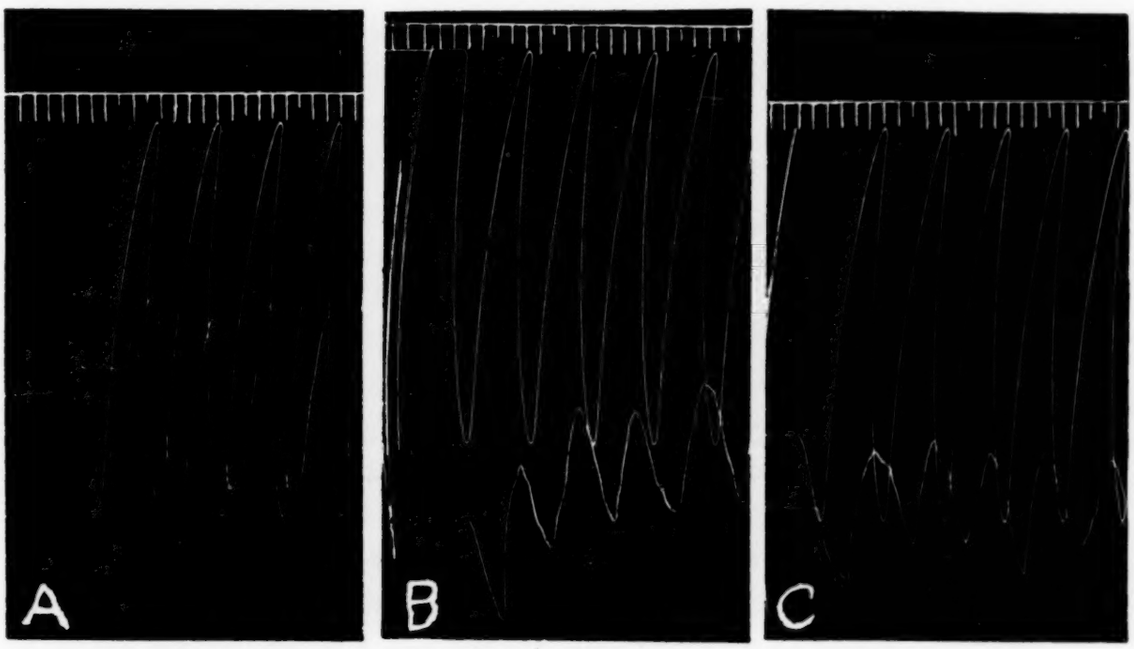


Fig. 1. Smoked drum records of oscillation of the platform (smooth curved lines) and voluntary manual response (irregular lines) with the subject blind-folded. Time line in seconds at the top. *A*—head inclined backward 45 degrees. *B*—eye-ear axis on the horizontal. *C*—head inclined forward 45 degrees. Platform oscillating 2 degrees at the rate of one complete oscillation in 4.5 seconds.

Records of the oscillations of the platform and the subject's manual response to the perception of motion were obtained by two levers marking on the smoked drum of a special kymograph which was mounted on the platform. Time was recorded in seconds. Figure 1 shows a typical record. The subject was instructed to move the response lever at the same rate and distance as his perception of the motion of the platform. This type of response, despite certain obvious inaccuracies, is the only way to indicate the direction, the amount of angular displacement and the rate of perceived motion.

The head was placed in three different positions in the sagittal plane, namely, eye-ear axis on the horizontal, head inclined forward with eye-ear axis at 45 degrees and head inclined backward with eye-ear axis at 45 degrees. Four trials were given each subject for each position of the head during each experimental session of about one hour in length. The intensity of vestibular stimulation was varied by varying the rate of oscillation of the platform. Three different rates were used, one complete oscillation in 9 seconds, 4.5 seconds and 3 seconds respectively. The angular displacement remained constant at 2 degrees. The constant-stimuli method was used and each subject responded to 10 successive oscillations during each trial. The three different rates were given at random together with a non-stimulation period for each position of the head. The subject was blind-folded during all trials and short rest periods were interposed between trials. The non-stimulation period was given to produce a keener state of attention. The subject knew that this trial would occur but he was kept in ignorance as to the order of trials. Very brief introspective reports were obtained immediately after each trial as a check on the voluntary response to perceived motion.

Results

Distributions of the amplitude of response on the smoked drum indicating approximations of the extent of bodily motion are given in Table 1. All frequencies above zero are positive responses or responses which are correct as to the direction of motion. All those below zero are negative responses and are incorrect as to direction. The amplitude represents extent and clearness of the perceived motion. The greater the rate of oscillation of the platform the greater the acceleration and deceleration and thus the greater the intensity of stimulation. It will be seen from Table 1 and Fig. 2 that the average amplitude of response is from 2 times to 4 times as great for the 3-second per oscillation rate than for the 9-second per oscillation rate, varying with the positions of the head. The rate of oscillation of 4.5 seconds for one complete oscillation approximates the 75 percent threshold for all three head positions, whereas the rate of 9 seconds is well below and the rate of 3 seconds is well above this threshold. These frequency distributions in Table 1 show extreme variability and

TABLE I

DISTRIBUTIONS OF AMPLITUDE OF RESPONSE FOR THE THREE POSITIONS OF THE HEAD AT THREE SPEEDS OF OSCILLATION (THREE SUBJECTS)

Amp. Mm.	Eye-ear Axis Horizontal			Eye-ear Axis 45° Head Inclined Forward			Eye-ear Axis 45° Head Inclined Backward		
	3″	4.5″	9″	3″	4.5″	9″	3″	4.5″	9″
34							1		
33				2					
32									
31							1		
30							3		
29	1						3		
28							8		
27	6			4	1		6	1	
26	3		1	3			5		
25	3						9	2	
24	7	1		4			7	7	
23	8	1		6	3		7	2	
22	12	3		9	3		11	3	2
21	10	2	1	4	3		10	7	2
20	17	2	1	13	5		18	6	2
19	14	3	5	10	2		11	8	1
18	14	6	1	4	5	1	16	6	6
17	14	6	1	11	8		14	8	3
16	23	4	1	12	9	1	17	6	4
15	15	9	1	21	5	4	19	11	3
14	14	6	1	13	12	6	10	12	3
13	16	13	1	17	6	1	13	18	7
12	17	16	2	16	12	2	13	14	14
11	16	22	6	15	14	2	5	16	7
10	11	14	6	10	15	11	16	16	9
9	4	21	3	7	15	3	8	3	9
8	8	23	6	10	18	8	8	10	15
7	1	14	8	8	11	17	7	5	2
6	12	15	12	10	15	8	2	7	11
5	8	7	14	6	15	13	4	9	8
4	3	11	13	6	10	8	3	6	9
3	1	6	5	3	10	9	5	4	6
2		6	14	4	3	9	2	3	7
1		6	14	1	12	14	2	4	15
0		5	41	6	9	41	3	4	24
− 1		2	6	1	3	6	1	1	3
− 2			5	3		5			3
− 3		1	2			3			
− 4		1		2	1	2			
− 5			3	1		1			1
− 6			1	2	1				
− 7									
− 8				1		1			
− 9			1	2		1			
−10				5					
−11									
−12									
−13				3					
−17				1					
Totals	268	226	176	256	226	177	268	199	176
Means	15.5	9.5	4	11.8	9.2	4	16	12.3	8
S. D.'s	5.5	5.2	5.7	8.5	5.9	5	7	6.1	6.1

yet certain definite trends are apparent. Reference to the curves in Fig. 2 shows that as the rate of oscillation increases the average amplitude of voluntary responses increases. This relationship approximates rectilinearity. Furthermore when the total average amplitude of response was taken for each head-position statistically significant differences were found between all three positions. Table 2 summarizes these data for the three different positions of the head and the critical ratios indicate statistically significant differences. The most

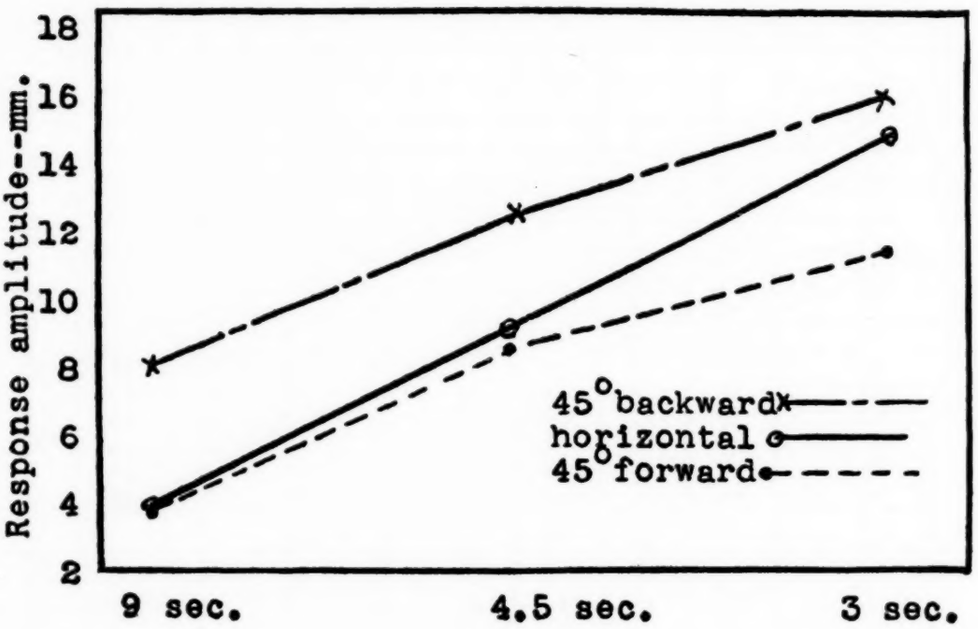


FIG. 2. Relationship between rate of passive oscillation of the body and amplitude of voluntary response to the perception of motion for three head positions.

Time for one complete oscillation.

Angular displacement of 2 degrees.

effective position is when the head is inclined backward 45 degrees and the least effective position is when the head is inclined forward 45 degrees. According to otologists the position which is most effective in stimulating the horizontal canals is when the head is inclined forward 30 degrees, whereas the most effective position for horizontal rotation to stimulate the vertical canals is when the head is inclined backward 60 degrees. In the present experiment when the head was inclined forward 45 degrees the horizontal canals were functionally most active and when the head was inclined backward

TABLE II

SUMMARY OF TABLE I (THREE SUBJECTS)

Position Eye-ear Axis	Number of Reactions	Mean	S.D.$_{dis.}$	S.D.$_{m}$	Critical Diff./S.D.	Ratios Diff.
1. Horizontal	670	10.4	5.3	0.20	(1) and (2)	5
2. 45° inclined forward	659	8.8	6.7	0.27	(1) and (3)	7
3. 45° inclined backward	643	12.7	6.5	0.26	(2) and (3)	10

45 degrees the two pairs of vertical canals were functionally most active. According to our experimental results the two pairs of vertical canals functioning together are much more effective than the horizontal canals in the perception of passive rotary motion of the body.

The fact that there is a significant difference between the horizontal position and the forward position of the head in amplitude of response suggests two possible interpretations.

TABLE III

DAILY VARIATION IN AMPLITUDE OF RESPONSE FOR THREE SUBJECTS FOR THE THREE POSITIONS OF THE HEAD

	Days	Head Positions		
		Eye-ear Axis Forward 45°	Horizontal	Eye-ear Axis Backward 45°
Subject R. N.	1	8.0	7.3	7.3
	2	8.7	8.7	11.7
	3	3.0	7.7	10.7
	4	8.0	10.0	14.7
	Av.	6.9	8.2	11.1
Subject J. V.	1	6.3	6.7	10.0
	2	9.7	7.0	10.3
	3	8.0	8.3	15.7
	4	3.3	7.3	5.7
	5	7.0	6.0	8.0
	6	9.3	15.0	5.0
	Av.	7.3	8.4	9.1
Subject R. T.	1	13.0	10.3	18.7
	2	11.3	10.7	20.3
	3	10.7	15.0	15.7
	4	14.0	13.0	15.3
	5	10.0	10.0	8.0
	6	12.0	13.3	13.3
	Av.	11.8	12.1	15.2

Either the horizontal canals are most effectively stimulated when the eye-ear axis is in the horizontal plane or the vertical canals are stimulated more when the eye-ear axis is in the horizontal plane than when the eye-ear axis is inclined forward 45 degrees, thus reenforcing horizontal canal stimulation. Because of the superiority of the position when the eye-ear axis is inclined backward 45 degrees over the other two positions the latter interpretation seems more plausible.

The daily variation in the amplitude of response for each subject for the three different head positions is given in Table III. Reference to this table will show that a rather wide daily variability occurred for all three subjects and that any one day's performance could not be taken as an accurate indication of the relative effectiveness of the different head positions which were studied.

Summary

The effect of three different positions of the head on the perception of passive motion of the body was experimentally determined for three subjects. A modification of the Dodge-rotation platform with manual response, a special headrest to vary the position of the head through 90 degrees and a kymographic recorder were employed. The three head positions were: eye-ear axis on the horizontal, eye-ear axis at 45 degrees head inclined forward and eye-ear axis at 45 degrees head inclined backward. Three different rates of oscillation, one complete oscillation in 9 seconds, 4.5 seconds and 3 seconds, respectively, together with a non-stimulation period were used for each position of the head. The angular displacement of the head and body was kept constant at 2 degrees. The direction, extent and rate of perceived motion were indicated by voluntary manual response while the subject was blindfolded. The main conclusions from this study may be stated as follows:

1. Statistically significant differences were found between all three positions of the head in the amplitude of voluntary response. In order of adequacy the three positions would be ranked as follows: eye-ear axis at 45 degrees head inclined

backward, eye-ear axis on the horizontal and eye-ear axis at 45 degrees head inclined forward.

2. Within the experimental limits, the faster the rate of oscillation thus the greater the acceleration and deceleration, the clearer the perception of passive rotary oscillation of the body and thus the greater the amplitude of voluntary response. For all three subjects and all three positions the relationship between amplitude of response and rate of oscillation approximated rectilinearity.

3. Great variability in the clearness of the perception of motion occurred from trial to trial and from day to day for all three subjects.

(Manuscript received April 20, 1938)

References

1. Dodge, R., Thresholds of rotation, *J. Exper. Psychol.* 1923, **6**, 107–137.
2. Travis, R. C., and Dodge, R., Experimental analysis of the sensori-motor consequences of passive oscillation, rotary and rectilinear, *Psychol. Mon.*, 1928, **38**, No. 175, 1–92.
3. Travis, R. C., Reciprocal inhibition and reenforcement in the visual and vestibular systems, *J. Exper. Psychol.*, 1929, **12**, 415–430.
4. Gurnee, H., Thresholds to vertical movement of the body, *J. Exper. Psychol.*, 1934, **16**, 270–285.
5. Kopetzky, S. J., *Otologic Surgery*. Hoeber, 1925. Pp. 237–240.

REVERSED LATERAL DOMINANCE IN IDENTICAL TWINS[1]

BY EDWARD T. RANEY

Brown University and Emma Pendleton Bradley Home

Studies of lateral dominance in identical twins have indicated a greater incidence of left handedness among twins than in the general population. Several investigators have observed that in many twin pairs, one individual was right handed and the other left handed. Similarly, it was found that with respect to many other characteristics, frequently one twin of a pair was the reversed image of the other. Asymmetric reversal has been reported in the crown whorl of the hair, dental irregularities, facial pattern, palm pattern, and finger prints. Such asymmetric reversal of several traits has been thought to be a crucial mark of distinction between monozygotic and dizygotic twins. However, Lauterbach (**8**) could not find a notably higher degree of similarity between twins showing asymmetric reversal than between other twins.

A controversy has arisen among students of twins as to whether reversed handedness is actually present in identical twins to a significantly greater degree than among fraternal twins. Dahlberg (**2**) reported that left handedness occurs in a considerably higher percentage of pairs of identical twins than of fraternal twins, while von Verschuer (**14**) found a greater percentage of left handedness among fraternal twins. Both Newman (**9**) and Hirsch (**4**) have confirmed Dahlberg's findings. Wilson and Jones (**15**), however, found about 11 percent of left handed individuals among both types of twins as compared with 6½ percent among the single born. Newman (**10**) combined the data of the studies of Dahlberg (**2**), Hirsch (**4**), Newman (**9**), and von Verschuer (**14**), in order to

[1] This study was made under the direction of Dr. Herbert Jasper, whose aid I gratefully acknowledge. In addition I wish to thank Dr. R. D. Allen, Assistant Superintendent of Providence City Schools, for his aid in securing the twin subjects.

get a more complete picture of the whole situation. The data of Wilson and Jones (**15**) were not included since minor degrees of left handedness were not reported in their study.

According to Newman's composite figures there were 24 percent clear cases of reversed handedness in 241 pairs of identical twins and only 15 percent clear cases in 274 pairs of fraternal twins. Handedness in these studies was determined by a report on the hand used in such activities as writing and throwing a ball. In Newman's later study (**10**) motor skill in 'wrist tapping' and 'finger tapping' tests was used as a criterion of lateral dominance. According to these tests, in fifty pairs of identical twins, Newman found 16 percent of clear reversed handedness, and 10 percent of right handedness in one twin of a pair and ambidexterity in the other. In fifty pairs of fraternal twins, however, there were only 7 percent of clear mixed handedness and 4 percent of right handedness in one twin and ambidexterity in the other. Similar percentages were found according to the report on handedness given by the mothers.

When the data from the mother's report and the motor skill tests were combined, 26 percent of the identical twins and 8 percent of the fraternal twins gave a clear picture of reversed handedness. In an additional 8 percent of the identical twins and in an additional 3 percent of the fraternal twins, one twin was right handed, the other ambidextrous. These data would seem to indicate that reversed handedness occurs somewhat more frequently in pairs of identical twins than in twins in general.

Reversed handedness might appear even more frequently in identical twin pairs, were it not for the general emphasis on right handed training, and for the desire of parents to have the twins as much alike as possible. When twins are reared apart, the percentage of reversed handedness is increased considerably. In 20 pairs of identical twins reared apart, eleven of the pairs exhibited a reversed handedness (**10**).

In a study of ocular dominance in identical twins, Rife (**11**) reported that out of twenty pairs of identical twins, 15 pairs were cases of partial or complete reversal.

In the present paper further data on reversed laterality of dominance are presented with especial reference to the findings of the phi-test. This test, based on the laterality of apparent movement in binocular perception, has been described by Jasper and Raney (**6**) with results obtained in a study of lateral dominance in a group of normal subjects. It was noted in particular, that the results of the phi-test of lateral dominance were not consistently similar to those obtained on tests of handedness or on tests of eyedness. Consequently it was assumed that, while the phi-test indicated a centrally determined factor with lateral dominance, it was not a test of either handedness or eyedness. For this reason, it was thought that if there is a tendency for reversed lateral dominance in identical twins, it might appear in the results obtained on the phi-test, even though it was not present in handedness and eyedness habits.

Procedure

The subjects were 17 pairs of identical twins, including 13 pairs of white boys, 1 pair of colored boys, and 3 pairs of white girls. The twin group was chosen not only on the basis of a hospital or physician's record of a single placenta at birth, but also on the basis of similarity of chromatic pattern of eye grounds. The age range was from 7 to 16 years. School grade range was from the third grade to the first year of senior high school.

Tests of four aspects of lateral dominance were employed. (1) A questionnaire of manual preference in activities usually performed with one hand, composed of twenty items from Koch's study, and reported by Koch (**7**), as having a correlation of .90 or more with tests of actual performance and a reliability of at least .90. (2) The paper sighting test of preference in monocular sighting (ocular dominance). The subject is required to look at the examiner's nose through a small hole in a piece of paper held by the subject at arm's length. The examiner stands about 15 feet from the subject. Reliability of the test is .93 (**6**). (3) The visual form and written word sections of the Van Riper Critical Angle Board test (**12, 13**), a test of lateral orientation during the copying of a form or the writing of a word simultaneously with both hands. Reliabilities of the tests are .76 and .78 respectively (**6**). (4) The phi-test, a test of the perception of direction of phi-movement when conditions for perception of movement both to the right and to the left are presented simultaneously. Reliability of this test is from .90 to .97 (**6**).

The procedure followed in testing the twins was first to present the phi-test according to directions previously described (**6**). This involved repeating the test until the subject gave a clear and consistent report on the direction of the phi-movement for both near and far fixation. Then the two parts of the Van Riper Critical Angle Board test were given according to Van Riper's directions (**13**). The angle of orientation was increased until one hand wrote clearly in mirror writing. For the purposes of this study a subject was classified as right or left only when there was clear mirror writing

on both forms of the test. These tests were followed by ten trials with the paper sighting test. Finally the 20 questionnaire items were presented orally and checked with the imaginary performance of the act by the subject. On the questionnaire, if the subject was right handed on 15 (75 percent) or left handed on 15 (75 percent) or more questions, he was classified as right handed, or left handed, respectively. A criterion of 75 percent was arbitrarily chosen to place the criterion of right and left above a chance distribution of choices. On the paper sighting test if 8 (80 percent) or more indications were right eyed or left eyed, the subject was classed as right eyed or left eyed, respectively. Again the criterion of 80 percent was chosen to eliminate the influence of a chance distribution of choices. The twins were taken to the psychological laboratory at the Bradley Home [2] for testing. All subjects were tested by the author.

Results

The records of the subject's actual performances on all the dominance tests are to be found in Table I. These results are summarized in Table II in terms of the comparative dominance of each pair of twins on the various tests.

From Table II it can be seen that on the phi-test all the twin pairs had reversed lateral dominance whenever reliable results could be obtained. On the other three tests, only from 12 to 24 percent of the group indicated clear reversed laterality of dominance in a pair of twins. The percentage of reversed handedness on the questionnaire, 12 percent, is somewhat less than that found by Newman (24 percent). This difference may be due, however, to the small size of the present sample as compared with that in Newman's summary. The difference between the percentage of reversed ocular dominance found in this study (24 percent) and the percentage found by Rife (75 percent), probably can be explained by the fact that Rife used different test criteria. Also, it has been found by Crider (1) that the amount of right and left eyedness appearing in a group is directly dependent upon the test used and the number of trials given.

In addition to the number of clear cases of reversed handedness in twin pairs on the questionnaire (12 percent), there is a larger group (41 percent), in which one of the twin pair was right handed and the other gave some indication of a left handed tendency. In all, 53 percent of the twin pairs showed a clear or possible indication of reversed laterality on

[2] A hospital exclusively for neurological and behavior disorders of childhood recently described in *J. Amer. Med. Assoc.*, 1936, **107**, 650–652.

TABLE I

RESULTS OF BEHAVIORAL TESTS OF LATERAL DOMINANCE IN IDENTICAL TWINS

Serial Number	Phi-Test	Critical Angle Board	Ocular Dominance	Questionnaire	Remarks
1 *A*	L. C.	L	10 L	19 L 1 A	
B	R. C.	R	10 L	20 R	
2 *A*	L. C.*	Mixed	10 R	20 R	Mother reported both originally L. H.
B	R. C.	Mixed	10 R	20 R	
3 *A*	R. C.	Mixed	10 R	20 R	
B	L. C.	Mixed	10 R	20 R	Left arm had been broken
4 *A*	R. C.	R	10 R	20 R	
B	L. C.	R	10 R	19 R 1 L	
5 *A*	R. C.	R	10 R	20 R	
B	L. C.	L	10 R	20 R	
6 *A*	R. C.	R	10 R	20 R	
B	L. C.	Mixed	10 L	18 R 2 L	Reports uses L. H. when R. H. gets tired
7 *A*	R. C.	Mixed	10 L	16 R 3 L 1 A	
B	L. C.	L	9 R	17 R 3 L	
8 *A*	R. C.	Mixed	10 R	20 R	
B	L. C.	Mixed	10 R	16 R 4 L	Confuses R. & L. easily
9 *A*	R. C.	Mixed	5 R 5 L	20 R	
B	L. C.	Mixed	10 L	20 R	
10 *A*	R. E.	Mixed	10 R	20 R	
B	L. C.	Mixed	10 R	20 R	Left arm had been broken
11 *A*	L. C.	L	10 L	19 L 1 R	
B	R. C.	R	10 L	19 L 1 R	
12 *A*	L. E.	L	10 L	19 L 1 R	
B	R. E.	R	10 L	20 R	
13 *A*	L. E.	Mixed	10 R	18 R 2 A	
B	R. E.	R	10 R	20 R	
14 *A*	L. E.	R	10 L	20 R	
B	R. E.	L. H. paralyzed	10 L	20 R	
15 *A*	L. C.	Mixed	10 R	19 R 1 L	Confuses R. & L. easily
B	R. C.	R	9 L 1 R	20 R	
16 *A*	R. C.	R	10 L	20 R	
B	one eye crossed	Mixed	10 L	16 R 4 L	
17 *A*	R. C.	R	9 L 1 R	20 R	
B	L. C.	R	10 R	19 R 1 A	

* Results questionable.

TABLE II

FREQUENCY OF REVERSED LATERALITY ON BEHAVIORAL TESTS

		Number of Twin Pairs	Percentage of Twin Pairs
PHI-TEST:	One right, one left	15	88%
	One right, one undetermined	1	6%
	Questionable results	1	6%
QUESTIONNAIRE:	One right, one left	2	12%
	One right, one left on several items	7	41%
	Both right on all items	6	35%
	Both left on all items	1	6%
	Both left on several items only	1	6%
CRITICAL ANGLE:	One right, one left	4	23%
	Both right	2	12%
	One right, one mixed	4	23%
	One left, one mixed	1	6%
	Both mixed	5	30%
	One right, one undetermined	1	6%
QUESTIONNAIRE AND CRITICAL ANGLE:	One right, one giving some indication of left dominance	6	35%
PHI-TEST, QUESTIONNAIRE AND CRITICAL ANGLE:	One right, one giving some indication of left dominance	6	35%
OCULAR DOMINANCE:	One right, one left	4	24%
	Both right	7	41%
	Both left	5	29%
	One left, one ambi-eyed	1	6%

this test. The remaining pairs had similar dominance patterns on the questionnaire.

In addition to the cases of clear reversal on the critical angle board (23 percent), there is a group of 30 percent of the pairs in which one twin gave a clear picture of right (four twin pairs), or left (one twin pair) dominance, while the other twin of the pair was confused in orientation. Thus 53 percent of the pairs showed a clear or a possible indication of reversed laterality, assuming that a mixed picture on the critical angle board is due to the influence of left dominant habits just as it has been assumed that the appearance of left indications on several of the test items of the questionnaire indicates a left handed tendency. Also, in an additional 30 percent of the pairs, neither twin of a pair gave a clear picture on the critical

angle board. Both twins of a pair gave a clear right dominance picture in only two pairs of twins (12 percent).

Twelve pairs (70 percent) of twins gave some indication of reversed laterality, either on the questionnaire or the critical angle board, six of which (35 percent), were reversed on both tests.

In comparing the results obtained on the phi-test with those of the questionnaire and the critical angle board, it is found that in all cases where reversed laterality is indicated on either of those tests (70 percent), a similar picture is obtained on the phi-test. There were 35 percent of the twins who gave a similar reversed picture on the phi-test, the questionnaire, and the critical angle board. Only one individual who gave slight indications of left handedness on the questionnaire was the right dominant twin on the phi-test.

There seems to be little or no correspondence in the results found on the ocular dominance test, and the other three indices of lateral dominance used in this study, especially with reference to reversed laterality in the twins. According to the results of this study, identical twin pairs tend to have similar rather than reversed patterns of ocular dominance.

Summary and Conclusion

It appears from the present results on identical twins that one twin is right dominant and the other left dominant in practically every case on the phi-test. Such reversals on the other tests of lateral dominance used in this study occur but seldom although a slight indication of reversal on both handedness and orientation may at times be found. Furthermore when some indication of reversal did occur on these tests, it was similar to the pattern obtained on the phi-test. In contrast to Rife's findings the present results show that in ocular dominance there is a tendency for twins to have similar dominance patterns.

The above results indicate that identical twins are not identical, but that in the nervous mechanism there is an underlying tendency for one twin to be the mirrored counterpart of the other.

The fact that there is a difference in the nervous mechanisms of identical twin pairs has previously been reported by Hunt and Clark (**5**) in their study of the startle response in identical twins. They found that there was a quantitative difference in the nature of the startle patterns of identical twins, and that in every case where tests for handedness were given, the twin showing the larger startle response was mixed in dominance, with some tendency to be left handed.

This situation raises the question of the advisability of treating all identical twins as identical, as is assumed in the co-twin control method in the genetic study of behavior, and it may explain why, in such a study as Day's (**3**), identical twins as a group are retarded in language development. If one twin had a tendency to be left dominant, then that twin has a different adjustment to make in a right handed environment. If an adjustment to a right handed environment by a left dominant individual has an adverse effect on development, then the left dominant twins would tend to bring down the group average. Studies of identical twins, separated into two groups on the basis of the dominance tendencies revealed by the phi-test, should give interesting results on the effect of lateral dominance on the comparative development of twins.

(Manuscript received April 6, 1938)

References

1. Crider, B., Unilateral sighting preference, *Child Develop.*, 1935, **6**, 163–164.
2. Dahlberg, S., *Twin births and twins from an hereditary point of view.* Stockholm, 1926.
3. Day, E. J., The development of language in twins, *Child Develop.*, 1932, **3**, 179–199.
4. Hirsch, N. D. M., *Twins: heredity and environment.* Cambridge: Harvard University Press, 1930. Pp. 159.
5. Hunt, W. A., and Clark, F. M., The startle pattern in children and identical twins, *J. Exper. Psychol.*, 1937, **21**, 359–362.
6. Jasper, H. H., and Raney, E. T., The phi-test of lateral dominance. *Amer. J. Psychol.*, 1937, **49**, 450–457.
7. Koch, H. J., A study of the nature, measurement and determination of hand preference, *Genet. Psychol. Monog.*, 1933, **6**, 117–221.
8. Lauterbach, E. C., Studies in twin resemblance, *Genetics*, 1925, **10**, 525–568.
9. Newman, H. H., Studies of human twins, II. Asymmetry, reversal or mirror-imaging in identical twins, *Biol. Bull.*, 1928, **55**, 298–318.
10. Newman, H. H., Freeman, F. H., Holzinger, K. J., *Twins: a study of heredity and environment.* Chicago: Chicago Univ. Press, 1937. Pp. 369.

11. Rife, D. C., Genetic studies of monozygotic twins, III. Mirror-imaging, *J. Hered.*, 1933, **24**, 443–446.
12. Van Riper, C. A., A new test of laterality, *J. Exper. Psychol.*, 1934, **17**, 305–313.
13. Van Riper, C. A., A new test of laterality, *J. Exper. Psychol.*, 1935, **18**, 372–382.
14. von Verschuer, Der Vererbungsbiologische Zwillingsforschung, *Ergeb. Innern Med. U Kinderholt*, 1927, **31**.
15. Wilson, P. T., and Jones, H. H., Left-handedness in twins, *Genetics*, 1932, **37**, 560–571.

SUBJECTIVE BRIGHTNESS IN RELATION TO FLASH RATE AND THE LIGHT–DARK RATIO *

BY S. HOWARD BARTLEY

From the Laboratory of Neurophysiology, Washington University, School of Medicine, St. Louis

With a revolving disc having a number of alternate black and white sectors, Brücke (1864) observed that at a frequency of 17.5 stimuli per second, the impression of brightness exceeded that of the white sectors when stationary. Helmholtz pointed out that the brightness was not uniform over the whole disc, but that it was interspersed with dark places which, he suggested, tended to make the white look brighter by contrast.

An enhancement of brightness may also be observed with a series of flashes. Their brightness will exceed that of steady light of the same physical intensity, if the repetitive rate falls within a range which is much below critical flicker frequency for ordinary intensities. We shall term this phenomenon of enhancement the Brücke effect, the opposite to the Talbot effect obtained with flash rates producing the sensory stationary state (that is, at or above the critical flicker frequency).

The question arises whether the photochemical formulations which have been applied to the one can be applied to the other to attempt to account for brightness discrimination. The assumptions underlying this paper are that photochemistry determines only the sense cell discharge and not the sensory outcome in the direct way currently claimed.

In photochemical formulations, a 'dark' process, regenerative and opposite in direction to the light process, is assumed. When the light-dark alternations in the stimulus cycle become rapid, they outrun the velocities of the two processes, and during each phase of the cycle the appropriate process is able

* This work was conducted under a grant from the Rockefeller Foundation for research in neurophysiology.

to do little more than to get started by the time the opposite phase begins. Thus, an almost stationary state is set up in which the fluctuations in the concentration of the light product x are so slight that they supposedly produce no variation in the rate of discharge in the sense cell. In this way, sensory continuity and uniformity are directly instituted by the sense cell itself, and it is supposedly behaving as if stimulated by steady light. Whether this is true has not been demonstrated.

Any simple relation between *sensory brightness* and frequency of sense cell discharge has looked so alluring as to be readily accepted everywhere. In many cases it has been mistaken for the known simple relation between stimulus intensity and frequency of sense cell discharge; and with short flashes, for the known simple relation between quantity of light (in the stimulus) and the number of sense cell impulses. But the distinctions should be kept in mind.

It is easy to understand how two opposing processes would produce a *lower* concentration of substance x than if the one producing it were acting alone, and thus give the Talbot effect. But it is not obvious how an *increased* concentration could thus be produced (regardless of the rate of alternation between light and darkness). It is not clear how the net result of the action of two opposing processes could exceed that of one process acting by itself, and thus produce the Brücke effect.

Talbot's law stating the relation between the time-intensity factors of stimulation and the sensory outcome was derived from flash frequencies at or above the point where flicker disappears. The results with lower flash frequencies are not predictable from the formulations handling the higher mentioned frequencies. However, they should be subject to the same set of principles, since we must presume that we are dealing with the same mechanism at all frequencies. This failure alone to account for the already demonstrated differences in flash brightness at different frequencies vitiates any theory that makes *brightness discrimination* a simple function of the *concentration of the light product x*. It can therefore be concluded, as a working interpretation at least, that the

parallel discovered between the two at c.f.f. was for all practical purposes fortuitous and has led to an erroneous and oversimplified conception of the institution of the sensory message.

The purpose of the present report is to demonstrate anew the existence of the Brücke effect and to find out how it varies with flash frequency and the ratio of light and darkness in the stimulus cycle.

Method

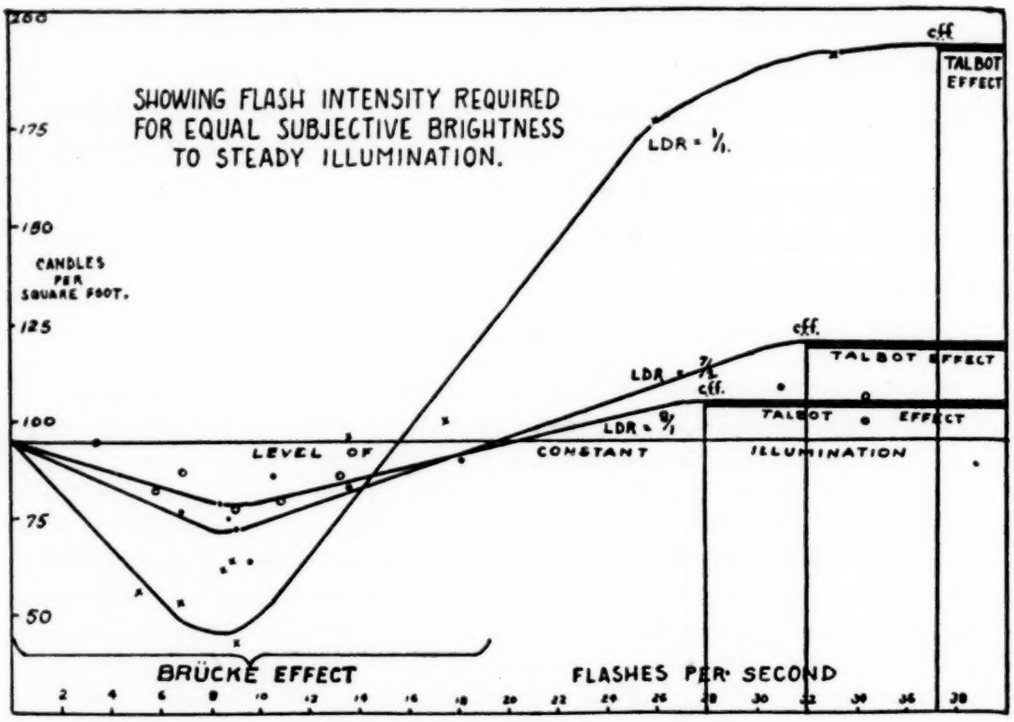
The relation of brightness to the stimulus variables was studied by use of two equal-sized fields, one of which was steadily illuminated, and the other intermittently, at rates from 3.4 to 40 per second. The intensity, which could be varied from 400 c/ft² to zero, was weak enough for the maximum rate just mentioned to exceed the critical flicker frequency (c.f.f.). The flash rate was set at various values, and a group of five or more readings was made at each during a given series. To make the readings at each sitting, the intensity of the flashes was adjusted so as to appear equal to the steady field. Three different light-dark ratios were used. Ratio 1 was 8 parts light and 1 dark; Ratio 2 was 7 parts light and 2 parts dark; and Ratio 3 was 1 part light and 1 dark (8/1, 7/2, and 1/1). Although the first two ratios gave smaller Brücke effects, they had less dark in them and were easier to deal with. The 1/1 ratio at slow rates of intermittency gave definite subjective superimpositions of light and dark phases. The attempt was made to take the net impression and not to judge the brightness of the bright phase. It would have been possible, on the other hand, to have judged the value of the flash as a more or less discrete entity. But if such readings had been taken there would have been a still greater contrast between the steady level and the intermittent. These were not used, however, for they would not have compared fairly to what was intended, an *average effect.*

The Brücke effect is definite enough for subjects who are entirely ignorant of the significance or purpose of the experiments to observe and make consistent readings on. This was shown by the fact that a twelve-year-old boy was brought into the laboratory and, after having only been instructed to match the two fields in brightness, succeeded in making a complete series of readings which compared favorably with the author's.

Results

Parts of the curves in Fig. 1 show the typical Brücke effect. Each represents the combined results of two sittings in which five readings were taken for each point indicated. Many other curves were made, both at this and at different intensities, and with three different separations of the steady and flickering fields. The outcome in such cases did not essentially differ from the situation shown in the figure.

It will be noticed that the maximum Brücke effect occurs at about 8 or 9 flashes per second, regardless of the *LDR* and the c.f.f., and is greater the smaller the fraction of the cycle



occupied by the flash (the smaller the *LDR*). The position of the maximum Brücke effect is also independent of the intensity levels we used. They ranged from 4.5 to 400 c/ft^2. The maximum Brücke effect and the Talbot effect are reciprocal. In other words, a 1/1 *LDR* at and above c.f.f. requires *twice* the physical intensity of flash as does a steady light to match it, but the same *LDR* requires only *one-half* the intensity when the flash frequency is in the region of the maximum Brücke effect.

With frequencies which are lower than c.f.f.—and they have heretofore been neglected—the Talbot effect begins to break down long before the frequencies drop to the range giving the maximum Brücke effect. Starting at c.f.f., the slower the alternations, the nearer the flashes approximate the intensity of continuous light. As the flashes are repeated more and more slowly, they reach equality with it, then exceed it more and more till the alternation frequency reaches 8 or 9 per second, where their brightness reaches a maximum. At rates below this they begin to dim down and finally return again to the brightness of continuous light at frequencies approaching zero.

Discussion

Since the Brücke effect, *enhanced brightness with slowly repeated flashes*, does not seem to be an outcome which can be understood in terms of photochemistry, but rather in neural terms, a possible mechanism for its production must be sought. We would anticipate that this optimal brightness might be brought about by an intrinsic periodicity in the visual pathway somewhere.

Bishop (**6**) found a periodic waxing and waning of the responses of the visual cortex in the rabbit at a rate of about five per second. This was the same rate at which the large spontaneous alpha waves appear in cortical records, and the same rate at which Bartley and Bishop (**1**) found certain components of the total cortical response to optic nerve stimulation to appear. Bartley (**2**) also studied this intrinsic rhythmicity and concluded that five per second was the fastest rate at which any single set of elements working together as a unit could be reactivated maximally. Stimuli applied at faster rates would be responded to, but by smaller waves, hence by fewer elements. The first few rapidly repeated stimuli bring about a temporal reorganization of activated elements due to intrinsic differences in recovery time, differences in threshold, etc. Soon the elements are temporally dispersed into several groups and are thus able to take turns in responding to rapidly repeated stimuli. Further subdividing of groups and further dispersal could supposedly continue as stimuli are made more and more rapid . . . up to the point where the total response pattern is as if the system were responding to continuous stimulation.

In this way, the visual mechanism can respond to stimuli of any rate but will respond most vigorously at a certain critical one, and this would seem to provide for what we have found in sensation as the Brücke effect.

Bishop (**6**) showed that strong stimuli were able to drive the visual system. That is, after a few repetitions, responses became maximal for the stimulus intensity used regardless of the phase of cortical periodicity in which the series was begun, just as when stimuli were tuned to it. Though this was only

definitely shown for strong stimuli, there is no reason to believe that weaker stimuli could not effect the same result. This would have to be the case for our hypothesis successfully to account for the Brücke effect.

This very same mechanism would provide for the Talbot effect also. That is, after the stimulus-sense organ-optic nerve activity relation demanded by photochemical or any other theory would be established, the central visual mechanism as outlined would not oppose or remodel it. It would take the peripheral output and not change it quantitatively if it is repeated rapidly enough not to come into resonance with the intrinsic periodicity of the system, in which the maximum synchronization takes place and maximum response is the result. In effect, five per second was found to be the "resonant" frequency in the rabbit, which frequency was identified with that of both the alpha rhythm and the rate of repetition of the components of a complete response to an isolated stimulus.

The alpha rhythm in man is somewhere in the order of 8 or 10 per second, so it is very likely that the Brücke effect is brought about by the very same mechanism that provides for maximum cortical responses in the rabbit.

The Brücke effect, then, if this be true, is determined centrally and is thus an example of brightness discrimination which is not determined in the eye, although it cannot be said to be 'psychically' determined. The phenomenon is only one of several that force the explanation of brightness discrimination into neurological terms. Others have recently been reported (Bartley, **3**, **4**, **5**).

Summary

Repeated flashes ranging from the very slow to critical flicker frequency were matched in brightness with steady light, in which case an enhancement of brightness above that of the steady level was found in slow repetition. This is essentially the same as was found by Brücke in 1864 with black and white sectored discs, and for this reason, in this paper it has been called the Brücke effect.

The maximum Brücke effect is the reciprocal of the Talbot effect and occurs when the stimuli are given at about 8 to 10 per second.

Inasmuch as the alpha rhythm has been identified with an intrinsic brain periodicity, at which rate enhanced cortical responses can be elicited, and inasmuch as the rate producing the Brücke effect and the rate of the alpha rhythm are the same, it is suggested that the brain mechanism whose rhythmic activity determines the rate of cortical responses produces the Brücke effect.

The Brücke effect, then, would be an example of brightness discrimination determined outside the eye but definitely not a process which can be given the vagueness of being 'mental.'

The present paper illustrates the connection between sensory experience and the electrical studies of the brain and central nervous system in which precisely controlled stimulation is employed, and how the data in both fields are necessary to account for facts which are obtained.

(Manuscript received April 19, 1938)

References

1. Bartley, S. H., and Bishop, G. H., The cortical response to stimulation of the optic nerve in the rabbit, *Am. J. Physiol.*, 1933, **103**, 159–172.
2. Bartley, S. H., Temporal and spatial summation of extrinsic impulses with the intrinsic activity of the cortex, *J. Cell & Comp. Physiol.*, 1936, **8**, 41–62.
3. Bartley, S. H., Some observations on the organization of the retinal response, *Am. J. Physiol.*, 1937*a*, **120**, 184–189.
4. Bartley, S. H., The neural determination of critical flicker frequency, *J. Exp. Psych.*, 1937*b*, **21**, 678–686.
5. Bartley, S. H., Subjective flicker rate with reference to critical flicker frequency, *J. Exp. Psych.*, 1938 (April).
6. Bishop, G. H., Cyclic changes in the excitability of the optic pathway, *Am. J. Physiol.*, 1933, **103**, 213–224.